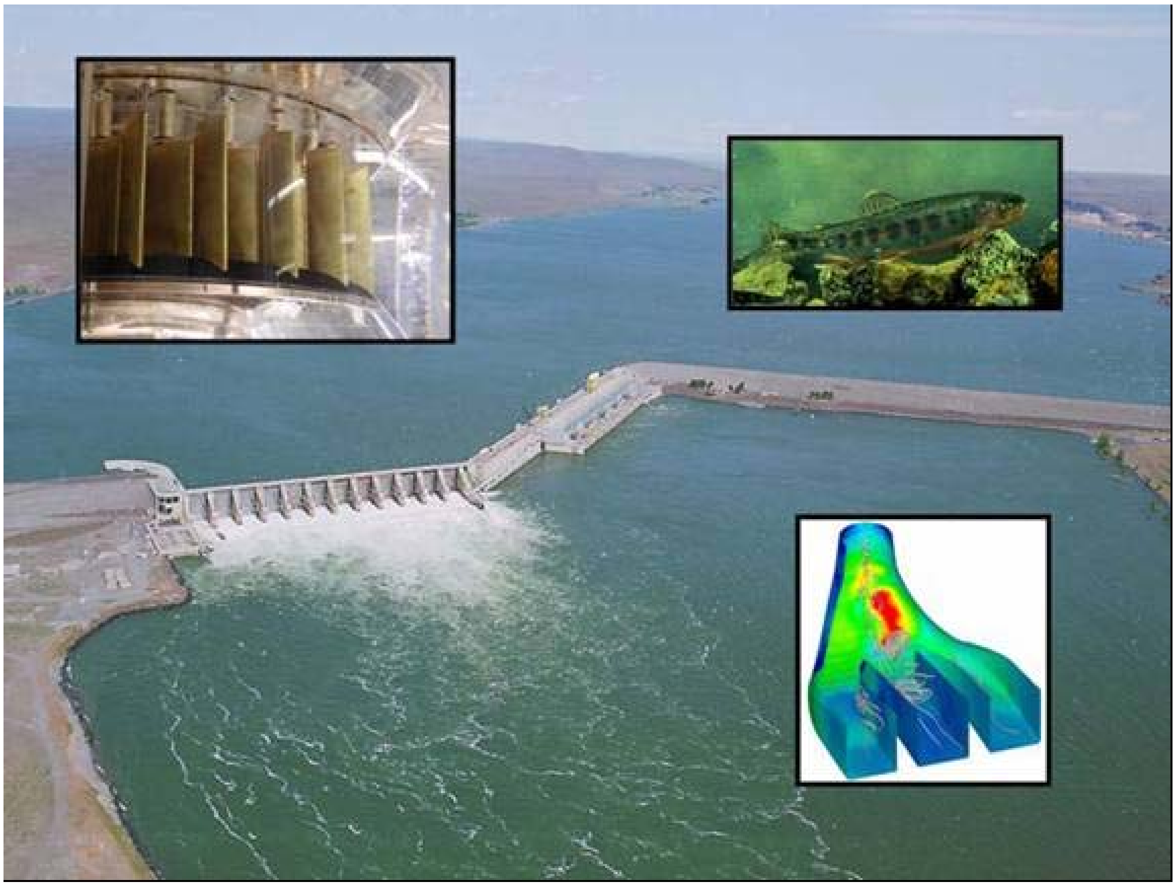
DOE/NE-ID-11220

DOE Hydropower Program Annual Report for FY 2004



U.S. Department of Energy
Energy Efficiency and Renewable Energy

Wind and Hydropower Technologies

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable.

DOE/NE-ID-11220

DOE Hydropower Program Annual Report for FY 2004

Garold L. Sommers[1]
Richard T. Hunt[1]
Glenn F. Cada[2]
Michael J. Sale[2]
Dennis D. Dauble[3]
Thomas Carlson[3]
James Ahlgrimm[4]
Tomas L. Acker[5]

February 2005

Prepared for the
U.S. Department of Energy
DOE Idaho Operations Office
Office of Energy Efficiency and Renewable Energy
Wind and Hydropower Technologies

---

[1] Idaho National Laboratory (formerly Idaho National Engineering and Environmental Laboratory)
[2] Oak Ridge National Laboratory
[3] Pacific Northwest National Laboratory
[4] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
[5] National Renewable Energy Laboratory

ACKNOWLEDGEMENTS

We acknowledge the contributions of numerous researchers who have been involved in DOE Hydropower Program activities: Chuck Coutant, Mark Bevelhimer, and Jim Loar (Oak Ridge National Laboratory); Doug Hall (Idaho National Laboratory); Fotis Sotiropoulos (Georgia Tech); Brennan Smith (Tennessee Valley Authority); Gene Ploskey, Tim Hanrahan, Russ Moursund, Mark Weiland, Kenneth Ham, Joanne Duncan, Robert Mueller, Richard Brown, Greg Guensch, Daniel Deng; and Marshall Richmond (Pacific Northwest National Laboratory); and Brian Parsons (National Renewable Energy Laboratory). The support of Peter Goldman of the U.S. Department of Energy is greatly appreciated.

SUMMARY

The U.S. Department of Energy (DOE) Hydropower Program is part of the Office of Wind and Hydropower Technologies, Office of Energy Efficiency and Renewable Energy. The Program's mission is to conduct research and development (R&D) that will increase the technical, societal, and environmental benefits of hydropower. The Department's Hydropower Program activities are conducted by its national laboratories: Idaho National Laboratory (INL) [formerly Idaho National Engineering and Environmental Laboratory], Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and National Renewable Energy Laboratory (NREL), and by a number of industry, university, and federal research facilities. Programmatically, DOE Hydropower Program R&D activities are conducted in two areas: Technology Viability and Technology Application. The Technology Viability area has two components: (1) Advanced Hydropower Technology (Large Turbine Field Testing, Water Use/Operations Optimization, and Improved Mitigation Practices) and (2) Supporting Research and Testing (Biological Design Criteria, Computer and Physical Modeling, Instrumentation and Controls, and Environmental Analysis). The Technology Application area also has two components: (1) Systems Integration and Technology Acceptance (Hydro/Renewables Integration, National coordinating Committee, and Integration and Communications) and (2) Supporting Engineering and Analysis (Valuation Methods and Assessments and Innovative Technology Characterization). This report describes the progress of the R&D conducted in FY 2004 under all four program areas. Major accomplishments in FY 2004 include the following:

- Conducted field testing of the Retrofit Aeration System, which is designed to increase the dissolved oxygen content of water discharged from the turbines of the Osage Project in Missouri. A 3D model of a portion of the Lake of the Ozarks was completed to predict dissolved oxygen patterns.
- Completed the design of the Wanapum project to install and test a minimum gap runner turbine.
- Evaluated technologies to observe fish and near neutrally buoyant drogues moving through turbines (Weiland et al. 2003).
- Completed study to understand fish injury mechanisms in order to identify designs and operational criteria for increasing the survival of fish passing through turbines (Ploskey et al. 2004).
- Evaluated indirect mortality as the consequences of fish passage through turbines (Ryon et al. 2004).
- Published *Hydropower Magazine 2004*.
- Further developed and tested the sensor fish measuring device at hydropower plants in the Columbia River (Deng et al. 2004). Data from the sensor fish are coupled with a computational model to yield a more detailed assessment of hydraulic environments at dams.
- Published *Water Energy Resources of the United States with Emphasis on Low-head/Low-power Resources* (Hall et al. 2004).
- Laboratory and DOE staff participated in numerous workshops, conferences, coordination meetings, planning meetings, implementation meetings, and reviews.

CONTENTS

FIGURES

ACRONYMS

AHTS	Advanced Hydropower Turbine Systems
BPA	Bonneville Power Administration
CFD	computational fluid dynamics
COE	U.S. Army Corps of Engineers
DOE	U.S. Department of Energy
DOF	degree of freedom
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDC	Engineering Research and Development Center
FERC	Federal Energy Regulatory Commission
IEA	International Energy Agency
INL	Idaho National Laboratory (formerly INEEL: Idaho National Engineering and Environmental Laboratory)
LIHI	Low Impact Hydropower Institute
MGR	minimum gap runner (turbine)
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PUD	Public/People's Utility District
OSTI	Office of Science and Technology Information
R&D	research and development
RAS	retrofit aeration system
SBIR	Small Business Innovation Research
STTR	Small Business Technology Transfer
TSP	Turbine Survival Program
WAPA	Western Area Power Administration

DOE Hydropower Program Annual Report for FY 2004

1. INTRODUCTION

This report describes the hydropower activities supported by the U.S. Department of Energy's Office of Wind and Hydropower Technologies during Fiscal Year 2004 (October 1, 2003 through September 30, 2004).

1.1 The Technology

Hydropower is one of the nation's most important renewable energy resources; it generates about 10% of the country's electricity and produces more than 75% of the electricity generated from renewable sources (EIA 2003a). The technology for producing hydroelectricity from falling water has existed for more than a century. It has significant advantages over other energy sources: it is a reliable, domestic, renewable resource with large undeveloped potential, and it emits essentially none of the atmospheric emissions that are of growing concern, such as nitrogen and sulfur oxides and greenhouse gases. Hydropower projects can offer substantial nonpower benefits as well, including water supply, flood control, navigation, and recreation.

Hydropower poses unique challenges in energy development, however, because its great benefits can be offset by environmental impacts. The environmental issues that most frequently confront the hydropower industry are blockage of upstream fish passage, fish injury and mortality from passage through turbines, and lowered quality and quantity of water released below dams and diversions.

The current capacity of hydropower in the United States is about 80,000 MW (EIA 2003a). Hydroelectricity is produced at about 180 federal projects and at more than 2,000 nonfederal projects, regulated by the Federal Energy Regulatory Commission (FERC), in all 50 states and Puerto Rico. Although there are substantial undeveloped resources in the United States, hydropower's share of the nation's generation is predicted to decline through 2020 to about 6%, due to a combination of environmental issues, regulatory complexity and pressures, and changes in energy economics. Only 560 MW of conventional hydropower capacity is expected to be added by 2025 (EIA 2003b).

1.2 The Hydropower Program

The U.S. Department of Energy (DOE) initiated the Hydropower Program in 1976 to support research and development that would produce technical and environmental guidance for improving operation and development of hydropower facilities in the United States. DOE national laboratories support the program: INL (engineering), ORNL (biological and environmental), PNNL (technology development / biological testing), and NREL (integration of hydropower and other renewable energy sources). Over the years, the program has supported research and development for low power hydropower projects, research on environmental issues and mitigation practices, development of advanced and environmentally friendly hydropower turbines, and hydropower resource assessments.

The Hydropower Program maintains close working relationships with private industry, national hydropower organizations, regulatory agencies, and other federal agencies: U.S. Army Corps of Engineers, Bonneville Power Administration, Tennessee Valley Authority, U.S. Bureau of Reclamation, U.S. Geological Survey, and NOAA Fisheries. These relationships allow DOE to better understand the needs of the hydropower industry, complement research being conducted by others, and leverage research and development funds through cooperative and cost-sharing agreements.

The program's contributions are summarized in regular annual and biennial reports (e.g., Cada et al. 2003). A description of the DOE Wind and Hydropower Technologies Program can be found on the Internet at http://www.eere.energy.gov/windandhydro/. Annual and topical research reports are available on the DOE Hydropower Program Website: http://hydropower.inel.gov/.

1.3 Mission and Goals

The program mission is to conduct research and development (R&D) that will increase the technical, societal, and environmental benefits of hydropower and advance cost-competitive technologies that enable development of new and incremental hydropower capacity, adding diversity to the nation's energy supply.

The Hydropower Program has two parallel goals, with a completion target date of 2010:

- Develop and demonstrate new technologies that will enable 10% growth in hydropower generation at existing plants, with enhanced environmental performance
- Conduct analyses and studies that will enable undeveloped hydropower capacity to be harnessed without constructing new dams or causing unacceptable environmental damage.

1.4 Program Organization and Management

The Office of Wind and Hydropower Technologies (DOE-HQ) is responsible for planning and organizing the DOE Hydropower Program. Its principal functions are program and policy development, budget formulation and justification, and overall program guidance and direction. DOE-HQ has the authority and responsibility for technical project direction and for contracting the research and development activities that support the program (through the DOE-Golden Field Office).

A concerted effort is made to coordinate the DOE R&D with that of other federal agencies and industry, including both private and public entities involved with hydropower development. An open peer-review process involving industry and environmental resource agencies ensures that stakeholders are involved and that high-priority research needs are being addressed. A technical committee is maintained to review progress, evaluate results, and ensure coordination with related R&D activities of other agencies and industry. This committee consists of experts from the hydropower industry and state and federal agencies.

In addition, reviews of specialists who are not members of the technical committee are obtained when appropriate. Active coordination yields situational awareness, avoids duplication of research, and creates synergy among related research efforts.

DOE national laboratories with experience in hydropower issues provide technical support to the program: Idaho National Laboratory (INL) [formerly Idaho National Engineering and Environmental Laboratory], Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and National Renewable Energy Laboratory (NREL). INL contributes engineering and program management. ORNL contributes environmental studies and computation. PNNL contributes biological and related studies (taking advantage of their experience and facilities for conducting tests on fish). And NREL contributes studies in the integration of hydropower with other renewables. A combination of industry, universities, and federal facilities conduct research activities for the Hydropower Program. Where federal facilities have the equipment and personnel to reduce the overall cost to DOE, they are used for conducting R&D.

2. FY 2004 ACTIVITIES

The activities of the Hydropower Program are placed into one of two technical categories—either into Technology Viability or Technology Application. Each of the two categories has two research areas (a total of four project research areas), each having several project areas and numerous projects. Figure 2-1 presents the goals of the two technical categories of the Hydropower Program and shows the program structure down to the project areas.

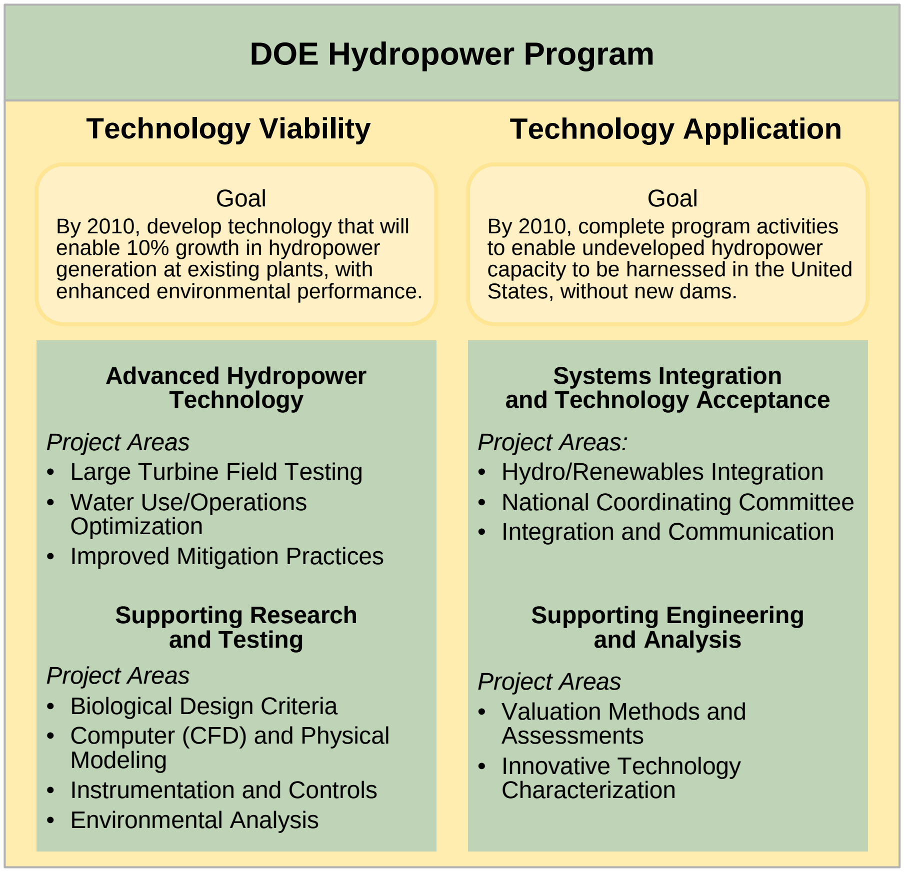


Figure 2-1. Organization of activities in the U.S. Department of Energy Hydropower Program.

2.1 Technology Viability

The mission of Technology Viability is to develop cost-effective technologies that will enhance environmental performance and achieve greater energy efficiencies. It addresses the following:

- Testing new turbine technology, analyzing test results, and reporting the test results and conclusions
- Identifying new technology efficiencies, effectiveness of water use, and opportunities for optimal plant operations
- Providing basic data and developing computer models that help define conditions of the water column inside an operational turbine
- Correlating plant operations with environmental and ecological conditions in the vicinity of hydro projects.

The goal of Technology Viability is to obtain sufficient data for industry to identify the values of new technologies and appropriately install them in existing projects, such that the overall hydroelectricity generation growth in the United States will be 10% by the year 2010.

The two research areas within Technology Viability are Advanced Hydropower Technology (summarized in Section 3.1) and Supporting Research and Testing (summarized in Section 3.2).

2.2 Technology Application

The mission of Technology Application is to conduct research and perform analyses that identify barriers to hydropower development and to devise strategies to reduce those barriers. It addresses the following:

- Quantifying technical issues, economic costs, environmental constraints, and benefits of integrating hydropower and wind operations
- Pursuing the establishment of a national hydropower coordinating committee with members representing all stakeholder and interest groups and that will elicit input concerning program issues and inform program direction
- Providing outreach and information transfer concerning program activities and R&D results to other agencies, industry, nongovernmental organizations, and the public
- Quantifying the varied benefits of hydropower to help the public and policymakers properly position hydropower in future competitive energy development considerations
- Evaluating unconventional turbine designs to address the undeveloped low-head/low-power potential identified in every region of the country.

The goal of Technology Application is to offer sufficient data by 2010 to enable industry to begin developing the untapped low-head/low-power potential in the United States without constructing new dams. The two research areas within Technology Application are Systems Integration and Technology Acceptance (summarized in Section 4.1) and Supporting Engineering and Analysis (summarized in Section 4.2).

3. TECHNOLOGY VIABILITY

The two research areas under Technology Viability are Advanced Hydropower Technology (Section 3.1) and Supporting Research and Testing (Section 3.2). The project areas within these research areas are listed and a discussion of the status of each project is presented thereafter. See Contents, page vii (Section 3), for a complete list of the projects.

3.1 Advanced Hydropower Technology

The project areas under Advanced Hydropower Technology are as follows:

- Large Turbine Field Testing (Section 3.1.1)
- Water Use/Operations Optimization (Section 3.1.2)
- Improved Mitigation Practices (Section 3.1.3).

3.1.1 Large Turbine Field Testing

This project area involves testing new-generation turbines for efficiency (compared with older machine efficiencies), compatibility with environmental requirements (i.e., dissolved oxygen concentrations and fish passage survival), commercial viability, and their success at balancing environmental, technical, operational, and cost considerations. The methodology involves designing field test protocols, performing baseline field tests on existing plant equipment and operation, installing new technology, conducting repeat field tests on the new technology equipment, and analyzing and comparing test data related to performance objectives.

3.1.1.1 Osage Plant

A retrofit aeration system (RAS) will be installed at AmerenUE's Osage plant at Bagnell Dam in Missouri. The aeration system was selected for testing as one of the new technical approaches available to enhance dissolved oxygen and improve water quality at hydropower facilities without the necessity for major civil works modifications and the purchase of expensive, self-aerating turbines. The R&D for this project involves cost-sharing the following tasks with AmerenUE (the site owner and operator):

- Designing the retrofit aeration system
- Developing the engineering and biological test protocol
- Conducting baseline engineering and biological field tests for present conditions
- Conducting engineering and biological field tests after the aeration system has been installed
- Developing an operation and maintenance (O&M) monitoring protocol
- Reporting on field test results and O&M issues and costs.

The present status of the project is outlined as follows:

- Installation of additional venting capability for Unit 6 (new 2001 Francis turbine) was completed in June 2002.
- Baseline field-testing of dissolved oxygen downstream from Unit 3 (vintage 1931 Francis turbine) and Unit 6 was completed in August 2002.
- The new nosecone design was completed in February 2003, and installation of the new nosecones on both units (3 and 6) was completed in March 2003.
- Postinstallation field tests of dissolved oxygen for both units were completed in August 2003.

- Design modification for the unit intakes to help improve the dissolved oxygen of the water entering the turbines from the reservoir was considered in September 2003 after the postinstallation August testing results were analyzed. Design options and a computational fluid dynamics (CFD) intake model were developed by June 2004.
- Multiple runs of the CFD model are currently underway, with calibrations and refinements based on field observations.
- The final report on all computational and field tests will be delivered in FY 2006. A final report of O&M data and costs is also expected in FY 2006.

The total cost of this project (including RAS system installation) is about $1,300,000. DOE is contracted to fund about 50% (or about $ 658,000). Through FY 2004, DOE has funded $476,000.

3.1.1.2 Wanapum

A minimum gap runner (MGR) turbine will be installed at the Wanapum Dam. The MGR was selected for testing as one of the new turbines available to the hydropower industry capable of meeting the goals of the Large Turbine Testing projects and reducing fish mortality at hydropower projects. The R&D effort for this project will involve cost-sharing the following tasks with the site owner and operator (PUD No.2 of Grant County):

- Designing the new turbine
- Developing the engineering and biological test protocol
- Conducting baseline engineering and biological field tests for present conditions with the original turbine in place
- Conducting engineering and biological field tests after the new turbine is installed
- Developing an O&M monitoring protocol
- Reporting on field test results and O&M issues and costs.

The updated schedule is as follows:

- Disassembly of existing Wanapum Unit 8: Complete
- Advanced turbine and parts manufacture: October 2004
- Advanced turbine installation: October 2004–January 2005
- Advanced turbine engineering index testing: February 2005
- Side-by-side biological study, advanced versus existing turbines: February–March 2005
- Biological study data review: April–July 2005
- Engineering/biological data results report: September–November 2005
- Decision on the installation of additional advanced units: September–November 2005.

The total cost of this project (including the new turbine, ancillary equipment, and installation labor) is about $ 18,200,000. DOE is contracted to fund about 13% (or about $ 2,352,000). DOE has provided $ 1,135,000 through FY 2004.

3.1.1.3 Box Canyon

A minimum gap runner (MGR) turbine will be installed at the Box Canyon Dam on the Pend Oreille River in Washington State. The MGR was selected for testing as one of the new turbines available to the hydropower industry capable of meeting the goals of the Large Turbine Testing projects and reducing fish mortality at hydropower projects. The R&D for this project involves cost-sharing the following tasks with the site owner and operator (PUD No. 1 of Pend Oreille County):

- Designing the new turbine
- Developing the engineering and biological test protocol
- Conducting baseline engineering and biological field tests for present conditions with the original turbine in place
- Conducting engineering and biological field tests after the new turbine is installed
- Developing an O&M monitoring protocol
- Reporting on field test results and O&M issues and costs.

A final schedule for the above tasks cannot be established until the new operating license for the project is issued by the Federal Energy Regulatory Commission. The date of issuance has been fluid for the past two years, and license issuance is not expected until FY 2006. On this schedule, project tasks would not be completed until FY 2009.

This total cost of this project (including the new turbine, ancillary equipment, and installation labor) is about $9,800,000. DOE is contracted to fund about 25% (or about $ 2,478,000). DOE allocated $300,000 to Pend Oreille during the past three years for this project. None of the $300,000 has yet been spent.

3.1.1.4 Department of Energy - Army Corps of Engineers Strategic Plan

Most advanced hydroelectric turbine research and development in the United States is supported by two Federal agencies: the DOE and the Army Corps of Engineers (COE). Starting in 1993, the DOE's Advanced Hydropower Turbine Systems (AHTS) Program has been promoting the development of environmentally beneficial turbines (e.g., those improving fish passage survival or increasing dissolved oxygen concentrations) while maintaining efficient electrical generation. This effort is now organizationally under the Technology Viability area of the DOE Hydropower Program, and has the specific goal to develop and demonstrate technologies that will enable 10% growth in hydropower generation at existing plants with enhanced environmental performance.

The North Pacific Division of the COE operates 21 large hydropower facilities as part of the Columbia River Basin federal hydropower system. The COE has the responsibility to optimize the safe passage of migrating fish at their dams while continuing to provide the Pacific Northwest with low-cost renewable energy. The COE initiated the Turbine Survival Program (TSP) in 1995 to investigate the biological performance of their hydroelectric turbines (and other facilities such as spill and bypass structures) in an effort to identify structural and operational alternatives that would optimize the biological performance of their facilities.

The common interests of DOE and COE (optimization of fish survival through turbines and low-cost, efficient production of renewable hydropower) make it desirable to maximize collaboration and minimize duplication in their R&D programs. This coordination ensued at the inception of the AHTS and TSP programs through shared memberships in technical advisory and working groups. Collaboration has occurred or will take place in several activities, including (a) observational (physical) turbine models, (b) computational fluid dynamics (CFD) models of the turbine and turbine discharge, (c) characterization of the turbine environment for fish passage, (d) characterization of fish response to turbine passage, (e) development of approaches to optimize both power production and fish safety for existing and rehabilitated turbine units, and (f) field testing of turbine performance assessment tools and methods. In order to better organize and structure the effort, a report was prepared that summarizes common R&D interests of the two agencies, relates ongoing activities to the goals of the AHTS and TSP programs, and sets a timetable for future R&D that will further the agencies' respective goals. This report constitutes a strategic plan for conduct of the two advanced turbine programs; it will be updated in future years as informed by research findings and developing needs.

3.1.1.4.1 Ice Harbor

This project includes conducting baseline field biological studies at the Ice Harbor Dam, constructing a new hydraulic test stand and constructing/testing a turbine model in the new test stand to evaluate improvements in fish passage effectiveness for new turbine designs. The new turbine designs are to be considered for installation at the Ice Harbor Project.

- The baseline field-testing of Ice Harbor Units 1, 2, and 3 will be conducted in FY 2006. The final report of the results of these tests will be distributed in FY 2007.
- The Froude hydraulic, observational "test stand," which is a 1:25 scale model of Ice Harbor Units 1, 2, and 3, will be completed in October 2004. This test stand will be used to test Kaplan turbine runner models, representing both existing and new designs. If tests of new designs are judged favorable, turbine runners of the new design will be considered for installation at Ice Harbor Units 1, 2, and 3.
- A turbine runner model of the existing Ice Harbor turbine design will be delivered in February 2005. Testing of this design in the Ice Harbor test stand is scheduled to begin in FY 2005; a report is scheduled for delivery in FY 2006.

DOE has supplied $734,000 for this project since FY 2000, and the COE is requesting an additional $714,00 through FY 2007 to complete the project (a total of $1,448,000 requested from DOE). Total project cost is $30,980,000 and is jointly funded by the DOE, COE, and the Bonneville Power Administration (BPA will provide about 90% of the total funding).

3.1.1.4.2 Stay Vane, Wicket Gate, and Draft Tube Studies (Lower Granite Dam)

Stay vane and wicket gate model studies were conducted from September 2000 through April 2003. The content of the final report has recently been expanded, which has delayed issuance of the report. The report will now include two sections: "Stay Vane – Wicket Gate Modeling Report" and "Draft Tube Modeling Report" (the full report is now described as *Stay Vane – Wicket Gate Comprehensive Report*). Draft tube modeling studies were completed in FY 2004. The final expanded report will be issued in FY 2005.

This $609,000 project was jointly funded by the DOE, COE, and BPA. DOE has contributed about 48% of the budget ($294,000).

3.1.1.4.3 Bonneville Project Turbine Model

This project involved constructing a 1:25 scale Bonneville First Powerhouse test bed, fabricating two turbine runner models to fit the Bonneville powerhouse test bed, conducting biological simulation tests of fish passage travel paths using neutrally buoyant beads, and analyzing the test data. The biologic modeling of the two 1:25 scale turbine models was conducted in 2002–03. One turbine model is a standard Kaplan runner, the other a minimum gap runner (MGR). Biological conditions encountered during 1999–2000 field tests at Bonneville were emulated during the model tests.

The purpose of the tests was to identify the most likely path traveled by fish through the turbine from three different test release points and at two different operating flows. The experiments consisted of releasing beads at the stay vanes and documenting their path through the turbine environment using neutrally buoyant beads and high-speed video photography. Using the highest resolution cameras available (1280 × 512 pixels, at 500 frames/sec), measurements of bead velocity and acceleration were made of sufficient accuracy such that boundary region estimates of these parameters could be characterized in locations such as draft tube splitters. Tests showed that flows through the draft tube were less turbulent at the maximum-rated operating level than within 1% of peak unit efficiency, possibly providing safer flow conditions for fish passage at the maximum-rated operating level. How the beads respond to flow field features such as turbulence, load levels, and release locations will help reveal insight into fish injury and mortality observed under field conditions at full-scale (prototype-scale) Kaplan turbines.

A draft report (*Characterization of Bead Trajectories through the Draft Tube of a Turbine Physical Model)* was issued for review in September 2004. The final report is expected in FY 2005.

This $427,000 project was jointly funded by the DOE and COE. DOE contributed about 30% ($130,000) of the budget.

3.1.1.4.4 Second-Year McNary Turbine Fish Survival Test

This project involved planning, design, and implementation of a second year of biological turbine testing at McNary Dam. The first-year test was conducted at a single operating point, which happened to be at a moderate blade opening with a moderate gap at the hub and blade tip. The second-year test included four operating points, two of which represented almost wide open and almost closed blade opening configurations. The other two test points were with the turbine/generator unit operating within 1% of peak unit efficiency. A pilot study with adult salmonids was also performed during these tests. The tests were performed in the spring of 2002.

The test results prove there is no relationship between discharge volume and fish survival, as was previously believed. Current COE hydropower project operations are within plus or minus 1% of peak unit efficiency, based on a belief that maximum fish survival is achieved within this operating range. This study shows that maximum fish survival actually occurs at an operating point well above the normal 1% limitation. This study should help resolve some unknowns about fish survival and aid in convincing regulators and others that increased fish survival is possible at hydropower plants while allowing greater flexibility in power operations. The final report was released in May 2004.

This $1,299,870 project was jointly funded by the DOE, COE, and BPA. DOE contributed $169,000 (about 13% of the budget); the COE contributed about 73%; and the BPA contributed about 14%.

3.1.1.4.5 ALSTOM MGR Turbine Model Test

ALSTOM will provide a fish-friendly MGR turbine runner model of their design to the COE Engineering Research and Development Center (ERDC) for testing in the Lower Granite physical test stand. The results from the ALSTOM runner tests will be compared to test results from a standard Kaplan runner conducted in the same test stand. Each runner will undergo tests at three different flow rates. Two of the selected flows relate to flow conditions of which biological testing was performed in the field at the Lower Granite project in 1995. The third flow point corresponds to the upper limit of the 1% efficiency range for the ALSTOM MGR. Testing will consist of observing neutrally buoyant beads passing through the turbine runner using high-speed video. Velocity distribution in the draft tube will also be measured.

It is anticipated that higher efficiency and greater fish survival will be indicated for the ALSTOM MGR design compared to the standard Kaplan turbine runner. Lessons learned from this should be applicable to most new Kaplan turbine designs. Testing is scheduled to begin in the spring of 2005, and the final report will be completed in July 2005.

DOE has contributed $266,000 for this project.

3.1.2 Water Use/Operations Optimization

3.1.2.1 Optimization Studies

Water use optimization is a new research direction for the Hydropower Program, initiated in 2004. Limited experience in large federal systems (e.g., TVA's hydropower improvement programs) and ad hoc expert opinion indicate that significant energy increases can be achieved through a combination of advanced monitoring and controls, systems modeling, and operational improvements. A strategic planning workshop on water use optimization was held in Hood River, Oregon, August 3–4, 2004, to explore the feasibility, need, and priorities for new optimization research for the hydropower industry. The 21 participants attending included optimization experts and other interested parties. The goal of the workshop was to identify areas of research and development that would improve the use of water at hydroelectric facilities. Improvements could be in the form of traditionally sought increases of energy and power and, also, in the form of better and more flexible adaptation to environmental objectives. Optimization of hydropower facilities and operation has been identified as a promising path to the enhancement of U.S. renewable energy production.

More than ten areas were identified at the workshop and prioritized as prospective research topics. The top-ranked R&D needs from the Hood River workshop are:

1. Operational benchmarking metrics for assessing system performance and developing standard methods to determine theoretical maximum benefits (energy, energy values, and environment)
2. Valuing nonmonetary costs and benefits of hydro facilities and operations: developing, demonstrating, and testing new methods that represent environmental benefits as objectives, as opposed to the traditional approach of considering them as constraints
3. Integrated modeling of water quality, temperature, sediment, and fish resources to provide the capability to globally optimize river basin water operations.

These initial priorities will be subject to additional vetting with industry before the final DOE research strategy is finalized. A draft workshop report was prepared and is being revised in response to comments from the participants.

3.1.3 Improved Mitigation Practices

3.1.3.1 Opportunities for Spill Reduction

A significant contribution to the DOE goal of increasing hydropower generation at existing plants by 10% would be attained if spill to transport salmon downstream in the Columbia River basin could be reduced or compressed in duration so more water could be used for generation. ORNL staff worked with Dr. Roger Mann, an independent economist of RMecon, Inc., to review the economics of spill and alternative fish-passage technologies at Columbia River dams. Mann is the principal author of the Northwest Power and Conservation Council's Independent Economic Advisory Board's report on the economics of spill in relation to biological benefits and the costs of new fish passage technologies using less spill. ORNL has been providing biological data for his economic analysis.

A draft report, *Spill at Hydropower Dams: Opportunities for More Generation and Increased Fish Protection,* was prepared in August and is being revised to address review comments. A platform paper, "Trade-offs among Turbine Passage, Fish Bypass and Spill at Hydropower Projects," was presented at the annual meeting of the American Fisheries Society. The principal conclusion is that curtailment of spill at only a few Columbia River projects would supply sufficient funds through additional generation to cover costs of installing new fish-passage technologies while ensuring equal or better fish survival and cost savings to the ratepayers.

3.1.3.2 Instream Flow Mitigation

For many years, reduced flow and extreme daily fluctuations in flow have been recognized as consequences of hydropower production having the potential to negatively impact fish communities below hydropower dams. Common mitigation to address these concerns includes minimum instream flow requirements and changing the operating mode from peaking to run-of-river. In 2004, we continued to analyze the costs (primarily in terms of lost power generation) and environmental benefits of flow modification.

To evaluate environmental benefits, we performed a comprehensive literature search for biological monitoring studies designed to evaluate the biological response following various forms of flow mitigation. We included studies in our analysis that presented at least a bare minimum of data necessary to detect an apparent biological response. Studies were considered sufficient for inclusion if they presented data from at least one year before flow improvement and one year after, two or more years of data immediately following flow improvement (with the assumption that any biological response would not likely happen immediately and would progress for a few or perhaps many years after flow alteration), or at least two years from the affected site and two years from a controlled site. Our search turned up 20 projects with studies that met our criteria. Twelve of the projects studied had enough data for us to subjectively conclude that a biological response to the flow enhancement had occurred; in each case, the response was positive. The data from the remaining projects did not reasonably suggest a probable biological response, either because there were no consistent trends, the data were inadequate, or other factors made it difficult to relate changes to flow enhancement. Data insufficiencies and confounding factors included lack of sufficient number of years of sampling (either pre- or postimplementation); other concurrent mitigation (e.g., tailwater aeration to improve dissolved oxygen); significant differences in background conditions among years (such as those related to meteorology, flow, or predator dynamics); and inability to differentiate change from natural variation. Our analysis suggests that without adequate planning, monitoring programs do not often produce data sufficient to detect environmental change. The amount of time and effort required for a definitive monitoring program is often more than most licensees and regulators are willing to endure.

In order to quantify the effects of flow mitigation on generation cost, we gathered flow and generation data for 15 hydroelectric projects with relatively new licenses that required a change in operation from peaking to run-of-river. We addressed two questions: (1) Has annual generation changed significantly since the new license was issued? and (2) Has the proportion of flow during peak hours decreased significantly? Preliminary results suggest that overall generation has remained the same, but generation during peak hours has decreased in most cases. A final report that synthesizes these and previous tasks will be completed in FY 2005.

3.1.3.3 Effects of Hydro Operations on Redd Temperatures and Emergence Timing of Chinook Salmon

In FY 2003 we began evaluating relationships between river discharge, hyporheic zone characteristics, and egg pocket water temperature in a Snake River fall Chinook salmon spawning area. The project (cost shared by Idaho Power Company and Bonneville Power Administration) was initiated to examine the potential for improving juvenile Snake River fall Chinook salmon survival by modifying discharge operations at Hells Canyon Dam. The potential for improved survival would be gained by increasing the rate at which early life history events proceed (i.e., incubation and emergence), thereby allowing smolts to migrate through downstream reservoirs during early- to midsummer when river conditions are more favorable for survival.

Interactions between river water and pore water within the riverbed (i.e., hyporheic zone) at each 14 spawning sites (Figure 3-1) were quantified through the use of self-contained temperature and water level data loggers suspended inside of piezometers. Fall Chinook salmon eggs were also incubated in the laboratory for the purpose of developing growth curves that could be used as indicators of emergence timing. The effects of discharge on vertical hydrologic exchange between the river and riverbed were inferred from measured temperature gradients between the river and riverbed, and the application of a numerical model.

Figure 3-1. Egg incubation basket used to monitor emergence timing of juvenile fall Chinook salmon downstream of Hells Canyon Dam.

Overall, we concluded that hydropower operations of Hells Canyon Dam during the 2002–2003 fall Chinook salmon incubation period, had an insignificant effect on fry emergence timing at the study sites. It appears that short-term (i.e., hourly to daily) manipulations of discharge from the Hells Canyon Complex during the incubation period would not substantially alter egg pocket incubation temperatures, and thus would not affect fry emergence timing at the study sites. However, use of hydropower operational manipulations at the Hells Canyon Complex to accelerate egg incubation and fry emergence should not be ruled out. Further investigation of the incubation environment of Snake River fall Chinook salmon is warranted based on the complexity of hyporheic zone characteristics and the variability of surface-subsurface interactions among dry, normal, and wet water years.

A final report was issued in September 2004, *Effects of Hyporheic Exchange Flows on Egg Pocket Water Temperature in Snake River Fall Chinook Salmon Spawning Areas*.

3.2 Supporting Research and Testing

The project areas under Supporting Research and Testing are as follows:

- Biological Design Criteria (Section 3.2.1)
- Computer (CFD) and Physical Modeling (Section 3.2.2)
- Instrumentation and Controls (Section 3.2.3)
- Environmental Analysis (Section 3.2.4).

3.2.1 Biological Design Criteria

3.2.1.1 Response of Fish to Turbulence

A report was published titled Further Tests of Changes in Fish Escape Behavior Resulting from Sublethal Stresses Associated with Hydroelectric Turbine Passage (Ryon et al. 2004). The report is based on swimming behavior tests conducted on uninjured rainbow trout that passed through the ARL/NREC pilot-scale runner and test loop. In previous laboratory studies (Cada et al. 2003), the C-start behaviors of fish exposed to either high levels of turbulence or anesthetic were significantly different than control fish at 1 and 5 minutes after exposure. The primary reaction was complete inhibition of the startle response. The inhibition was short-lived; by 15-min postexposure, treatment fish reactions were no different than those of control fish. In predator preference studies, fish exposed to turbulence or anesthetic were also significantly more likely than control fish to be consumed, indicating that the diminished escape behavior observed with high-speed cameras coincided with increased losses to predation. Passage through a pilot-scale turbine altered some components of the escape behavior, although not to the degree seen in laboratory studies of turbulence. Passage through the pilot-scale turbine loop did not eliminate the startle response, but significantly extended the initial reaction time and the execution of the C-shape formation at 1- and 15-min postexposure. Such an alteration in a fish's escape behavior is likely to render it more vulnerable to predators.

A laboratory apparatus was constructed to examine the effects of exposure to larger-scale vortices (1-m diameter) on rainbow trout behavior. Experimental designs were drafted for evaluating changes in C-start behavior as potential indicators of indirect turbine effects on downstream migrating salmonids at Wanapum Dam.

3.2.1.2 Protocols for Biocriteria Development

Experimental protocols were prepared for the systematic study of two turbine passage injury mechanisms: turbulence and strike. A report titled *The Damaging Effects on Fish of Turbulence at Hydropower Plants – Protocols for Laboratory Experiments* discusses useful operational expressions of turbulence and biological endpoints, and suggests five experimental approaches for evaluating the consequences of turbulence associated with turbine and spillway passage. In addition, a report titled *Laboratory Experiments to Quantify the Effects on Fish of Strike During Hydroelectric Turbine Passage* reviews existing strike studies and suggests six experimental approaches for developing information that could be used in the design of advanced turbines to reduce this potential fish injury mechanism. Potential laboratory study sites for turbulence and strike experiments were identified.

A standard protocol was drafted for critical swim speed tests as a biological performance measure for hydropower improvements (especially new turbine testing). Swimming performance tests address critical questions about latent (not directly lethal) effects of turbine passage that could affect subsequent survival. It was drafted for comparative studies such as the new Wanapum Dam MGR turbine test. This protocol is an outgrowth of extensive technical review of swimming speed data for use in regulating water intakes (primarily for EPRI and EPA, and related to both cooling water and hydropower intakes).

3.2.1.3 Cumulative Effects of Multiple Hydropower Stressors

A likely contributor to unaccounted-for mortalities of juvenile Columbia River salmonids (and migratory fish in other river systems) is the chronic and often intermittent exposure to a variety of dam-related environmental and physical stressors that, although not directly lethal, often result indirectly in latent mortality. The overall objective of this study is to understand the cumulative or combined effects of multiple, sublethal stressors (e.g., high temperature, physical trauma, supersaturated gasses, and low dissolved oxygen) experienced by fish at some hydropower dams. In 2004 our goal was to develop a framework for using multiple indicators of stress to evaluate the combined effects of exposure to multiple stressors simultaneously or in succession. A draft report was produced that describes how a bioindicator approach could be used to assess cumulative effects and that also describes the results of preliminary laboratory experiments.

The laboratory experiments examined the dynamics of bioindicator expression in response to exposure to a single stressor, high temperature. Thermal stress experiments with 80 rainbow trout were completed at the beginning of August. Treatments included exposure to high temperature (25°C) for different durations (1 and 2 weeks) followed by periods of recovery when fish were returned to an unstressful temperature. Blood and gill tissue samples were collected throughout the study from eight fish at a time and analyzed later for hematocrit, leukocrit, cortisol, chloride, and stress protein expression (Figure 3-2). The statistical analysis of the analytical results is not fully completed, but preliminary review of the data suggests that the stress proteins are a more useful bioindicator of stress than are cortisol and chloride.

Figure 3-2. Drawing blood from a rainbow trout for analyses of stress indicators.

In 2005, the bioindicator approach will be tested as part of a larger study to evaluate turbine passage survival through a newly installed minimum-gap turbine at the Wanapum Dam on the Columbia River. Bioindicator responses of fish passed through an existing turbine will be compared to fish passed through a newly installed turbine designed to minimize fish trauma.

3.2.1.4 Cumulative Passage Effects on the Survival of Juvenile Salmonids

Survival of migratory juvenile salmonids passing through the turbines at hydroelectric dams is generally lower than for those passing through spill or bypass routes. If surviving turbine-passed salmonids do not recover fully, survival during subsequent turbine passage events may be lower than expected. Such a decrease in survival would constitute a cumulative effect. The primary objective of this project is to assess the potential of cumulative effects to reduce the population as a whole. To accomplish the objective, we need to know how many fish are at risk and to what extent survival rates decrease.

Our approach is to simulate fish passing the myriad of potential trajectories in the Snake and Columbia River system and to estimate their survival across a matrix of water flows and operational strategies. Yearling and subyearling Chinook and steelhead were apportioned among passage routes at each hydropower dam on the basis of historical trends for high, normal, and low water years, and with transportation (barging of fish past most dams) turned on or off. To evaluate whether cumulative effects would pose a substantial risk to the population, we simulated survival reductions on second and subsequent turbine passages from zero to 100%.

Results indicate that subyearling Chinook salmon have a much higher probability of passing multiple turbines than the other run-types or species evaluated. Transportation greatly influenced the number of fish exposed to multiple turbines, especially in low water years. In the absence of transportation, water year was also influential. Under all but the most extreme combinations of operational factors, high decrements for second and subsequent turbine passages were required to influence the overall number surviving to below the most downstream dam by an arbitrary 5% or more. Survival estimates for drought years reflect a high proportion of multiple turbine passage and place realistic bounds around the level of decrement. Once those bounds are set, we can delineate combinations where cumulative effects might be important, if any. The results of this project, once completed in FY 2005, can be applied to operate the hydropower system for increased survival of migrating juvenile salmonids.

3.2.1.5 Quantification of Hydraulic Forces

This project builds on previous studies that provided biological criteria for turbine design. The objective is to further quantify the hydraulic forces and physical stresses associated with injuries observed in turbine-passed fish. It has strong linkages to other programmatic components, including sensor fish development and biomechanics CFD (computational fluid dynamics).

In FY 2004 we completed the 3-D motion tracking analysis on the high-speed, high-resolution digital videos of juvenile salmonids exposed to a laboratory-generated shear environment to isolate injury mechanisms, and we evaluated parameters with multinomial and binomial statistical models. Threshold levels were estimated and a process for linking sensor fish data, laboratory exposures, and CFD results was initiated. We determined that bulk acceleration (~force) of the fish was most predictive of all injury types and overall injury level (Figure 3-3). The probability of minor injury, or worse, increased quickly starting at 100 $m \cdot s^{-2}$ and reached nearly 1.0 by 900 $m \cdot s^{-2}$. The probability of major injuries was similarly shaped, but increased by about 200 $m \cdot s^{-2}$ toward higher accelerations. The expected probabilities of an eye or operculum injury were similar, and increased slowly at low acceleration levels and became linear beyond 700 $m \cdot s^{-2}$ (Figure 3-3).

An article titled "Survival Estimates for Juvenile Fish Subjected to a Laboratory-Generated Shear Environment" was submitted to the *Canadian Journal of Fisheries and Aquatic Sciences* that reports our high-speed video analysis of fish exposed to shear and total force acting on those fish. The upcoming Waterpower XIV conference accepted an abstract that documents the initial correlation between sensor fish device data and live fish tests.

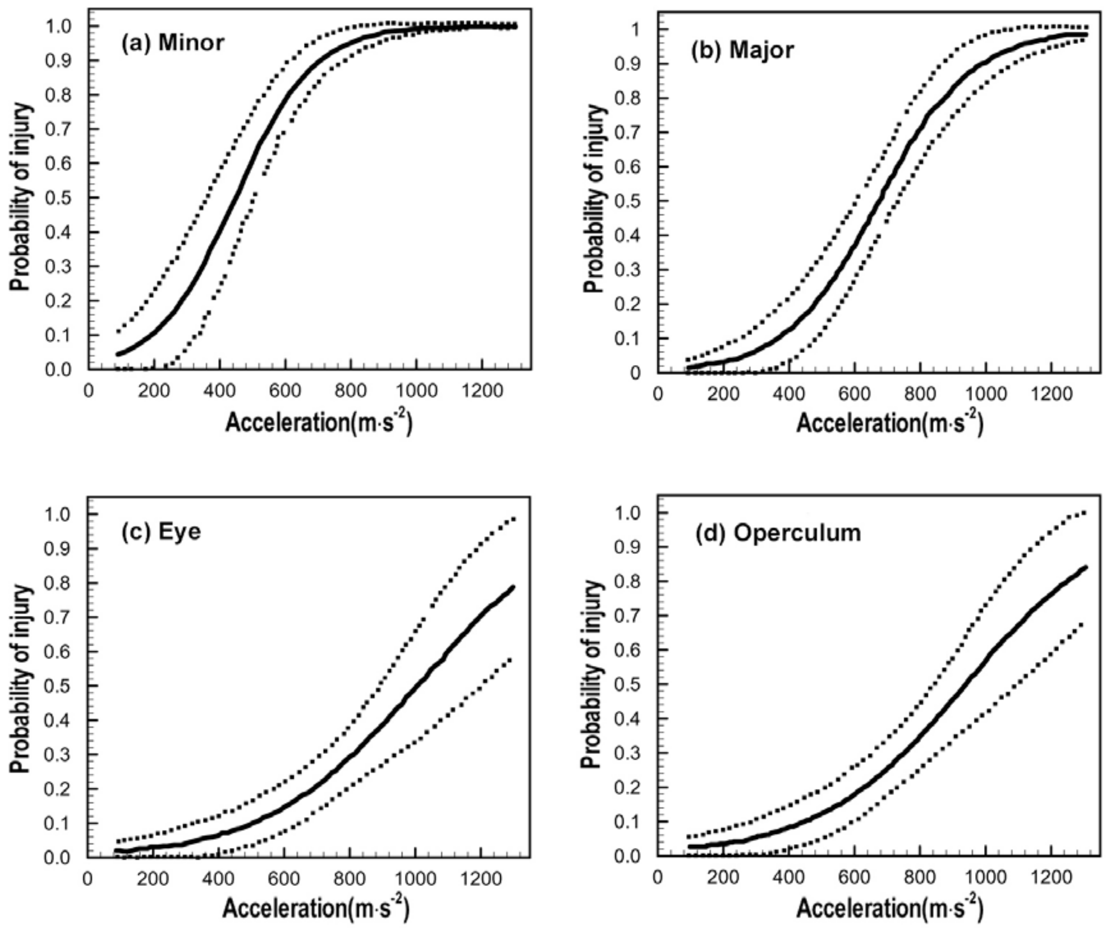


Figure 3-3. Fitted probability of four types of injury as a function of acceleration, with 95% predictive confidence intervals, as derived from binary logistic regression.

3.2.1.6 Biological Index Testing

Biological index testing is the systematic assessment of the biological performance of hydroturbines to identify operations for individual units and clusters of units with a goal to optimize total turbine passage. The objectives of this project are (1) to investigate the use of mathematical and physical models to identify the operating range of best biological performance (i.e., lowest risk of injury) for fish passing through hydro-turbines and (2) to design field tests using live fish to validate the proposed operating ranges.

During FY 2004, using a deterministic blade-strike model, we completed the modeling of the probability of blade strike, and associated injury, as a function of fish length and turbine operating geometry at two adjacent turbines in Powerhouse 1 of Bonneville Dam. In addition, the stochastic version of the model was implemented to evaluate the uncertainties and sensitivity of predictions to major input factors such as fish length, discharge, and passage location. A final report, *Comparison of Blade-Strike Modeling Results with Empirical Data*, was published in March 2004.

The extraordinarily high cost of live fish tests limits their use at prototype scales in the field. Use of physical and numerical models is required to develop testable hypotheses that define probable optimum biological performance ranges and expectations for fish survival metrics. Studies with physical turbine models reveal the rates of exposures such as collisions on stationary structural elements, strike by turbine blades, entrainment in highly turbulent and shear zones, etc. Because exposure events measured in the laboratory may differ from live fish, we initiated an assessment of the response of dimensioned particles to hydraulic forces in scaled physical models and fish passage issues at prototype scales. This work will be available for review in early FY 2005.

In FY 2005, we will continue to evaluate the validity of using strike and blade proximity observations in physical models and prediction using math models as reliable estimates of the biological performance of turbines. Our blade-strike models will be applied to the original McNary turbine runner physical model and predictions will be compared with the McNary physical turbine model bead data. In addition, we will estimate the relative and absolute biological performance of original design and advanced MGR design turbines at Wanapum Dam and compare predicted results with the empirical live fish and numerical results. This "hindcasting" is an effective means to assess the reliability of our approach to biological performance prediction and allows us to avoid additional high-cost field tests.

3.2.2 Computer (CFD) and Physical Modeling

3.2.2.1 Validation of the 3D Unsteady Turbulence Flow Solver

The development and application of the 3D unsteady turbulence flow solver continues, with emphasis on the assessment of various turbulence modeling strategies and the analysis of the unsteady features of draft-tube flows as they emerged from the simulations. Research findings were published through journal articles and conference proceedings (see List of FY-04 Publications). The Georgia Tech code is the most advanced unsteady turbulence simulation tool available today and is now ready to study turbulence at the size scale of a fish in hydropower installations.

The following were accomplished in FY 2004:

1. Swirling flow in the TVA Norris draft-tube at Re = 1.1×10^6 was simulated on a fine computational mesh (1.8 million grid nodes). Both unsteady RANS (URANS) and the hybrid URANS/DES turbulence modeling approaches were employed. Both approaches yielded complex unsteady solutions. Analysis of the computed results confirmed the existence of well known flow instabilities, such as the draft-tube rope vortex, and further revealed new phenomena, such as the rotating separation regions downstream of the runner (Figure 3-4).

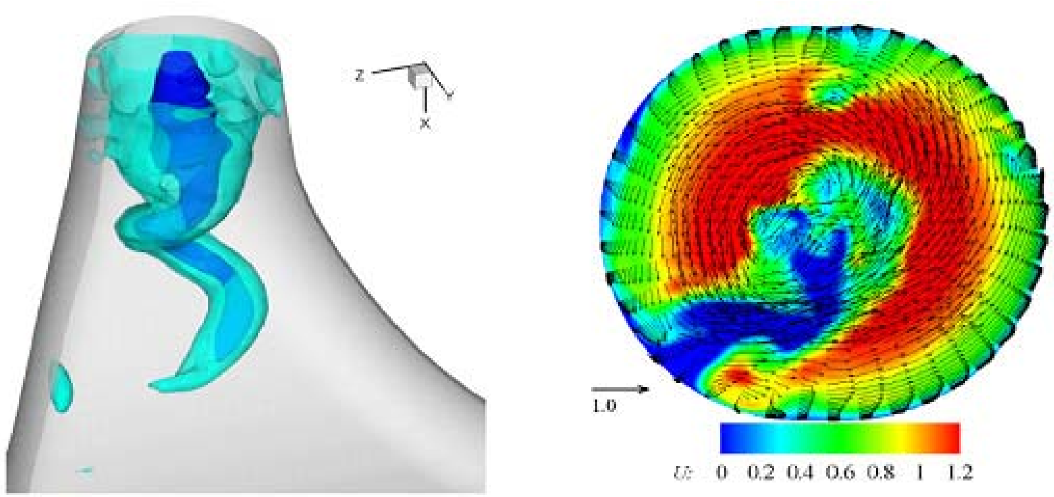
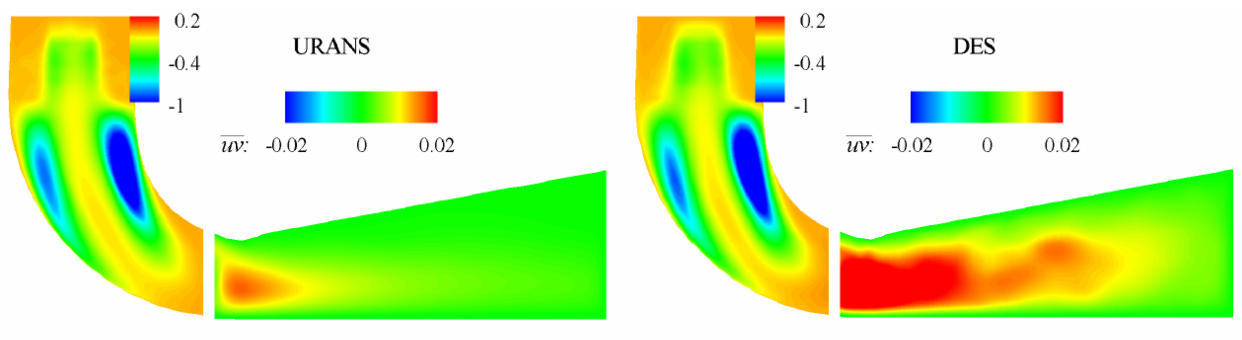


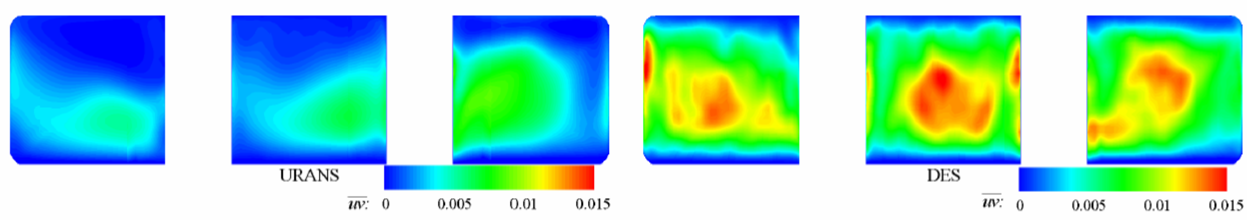
Figure 3-4. Precessing rope vortex downstream of the runner visualized in terms of an iso-surface of constant pressure (left); cross-flow vectors and streamwise velocity contours depicting a rotating

separated flow pocket that erupts from the draft-tube wall and gets entrained by the swirling flow (right).

2. Comparisons of the URANS and DES results revealed significant differences in the predicted turbulent statistics in the region downstream of the draft-tube elbow (Figure 3-5). The URANS simulation yielded very weak unsteadiness in this region, whereas DES predicted intense, low-frequency unsteady structures. Both methods yielded similar overall good agreement with a limited number of streamwise mean velocity measurements.



(a)



(b)

Figure 3-5. (a) Contours of turbulent Reynolds shear stress $-\overline{uv}$ calculated by URANS (left) and DES (right) at the vertical symmetry plane and (b) a cross-plane near the exit of the draft tube.

3. We completed the development and validation of an immersed boundary algorithm for simulating the flow past swimming and maneuvering fish. The algorithm was validated by applying it to simulate flow induced by a 3D robotic wing; the calculated lift and drag forces acting on the wing were shown to be in excellent agreement with the measurements. The accuracy of the algorithm was further demonstrated by applying it to reproduce well-known effects of certain kinematical parameters on the wake structure of swimming fish. Our calculations show that, in agreement with the experimental observations, a thrust wake develops when the speed at which the undulatory body wave propagates is greater than the swimming speed of the fish. The results of our research were presented in one conference proceeding and two journal papers.

3.2.2.2 Bioresponse (Computational Fluid Dynamics)

Previous studies have shown that fish can be directly injured or killed by exposure to shear and turbulence and that temporary disability, such as stunning, increases indirect mortality by predation. These bioresponse studies relate, in a general manner, fish injuries to the fluid environment; missing are detailed measurements and computations required for improved understanding of the biomechanics of injury mechanisms and injury thresholds.

In FY 2004, we developed an inertial particle tracker code with several features having application to biological response of fish during dam passage. These features include collisions with boundaries (with a variable coefficient of restitution), tracking on structured or unstructured CFD grids, stochastic motion using a subgrid scale turbulence scheme, efficient computational algorithms for particle locations in large computational grids, and the ability for each particle to record its exposure history to variables (pressure, etc.) and events (shear, collisions, etc.) in a simulated turbine environment (Figure 3-6). Planned enhancements in FY 2005 include incorporating sensor fish data, a more advanced turbulence scheme, and increased computational efficiency.

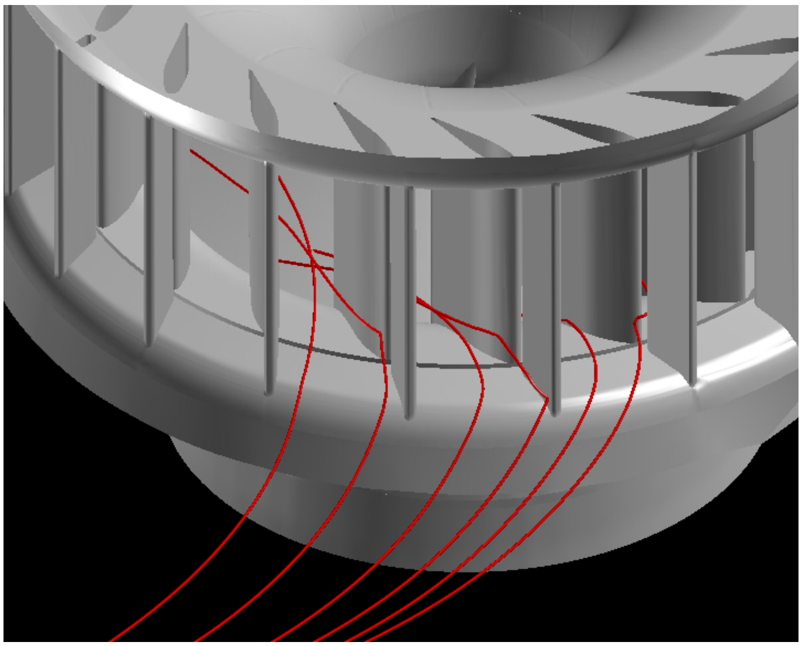


Figure 3-6. Detailed perspective view of a subset of the computational sensor fish particles. Note that several collisions with stay vanes and wicket gates occur.

Also during FY 2004, we performed initial simulations of a complete Kaplan turbine system (using Lower Granite Dam geometry), including the intake, moving runner, draft tube, and tailrace using the STAR-CD CFD code. The unsteady CFD simulations were run on the PNNL SGI Altix supercomputer. Simulation output provide flow field data to the 6DOF particle tracker and the blade strike modeling effort in the BioIndexing project. A key activity in FY 2005 will be to collaborate with the Corps of Engineers to obtain validation data in the DOE-funded Ice Harbor 1:25-scale turbine physical model.

In parallel with the computational work, we conducted a set of experiments (see Quantification of Hydraulic Forces, Section 3.2.1.5) using high-speed imaging to correlate sensor fish acceleration histories to the biological response of live fish. In FY 2005 we will conduct additional experiments using the new 6DOF sensor fish. These laboratory correlations, CFD, and the computational sensor fish analog offer a method to estimate biological response in complex turbulent flows.

3.2.3 Instrumentation and Controls

3.2.3.1 Pressure-Sensitive Film Applications

A manuscript titled "The Use of Pressure Sensitive Film to Quantify Sources of Injury to Fish" (Glenn Cada, John Smith, Jessica Busey) was accepted for publication in the *North American Journal of Fisheries Management*. The paper describes (a) laboratory evaluations of pressure-sensitive film and

(b) the use of this film in exploratory tests to characterize strike forces in the spill of two hydropower plants in the Columbia River. Based on the positive results of these tests, a Topaq pressure analysis system (film scanner and software) was acquired. This equipment will permit rapid and more thorough processing of pressure-sensitive film exposed to experimental pressures associated with mechanical (strike) or fluid forces (shear stress and turbulence).

3.2.3.2 Advanced Imaging

A major challenge toward evaluating the biological performance of operating turbines is to determine the interaction of fish with turbine structural elements, because these regions have high velocities, are highly turbid, and difficult to access. This project addressed these issues with the goal to identify and evaluate imaging alternatives for observing details of fish behavior within an operating Kaplan turbine unit.

The physical and hydraulic environment that fish experience as they pass through the turbines, including the physical structures of the intake, stay vanes, wicket gates, and runner, were studied, and the regions with greatest potential for injury were defined. Biological response data were also studied to determine the probable types of injuries sustained in the turbine intake and what types of injuries are detectable with imaging technologies. The physical constraints of the environment, together with the likely types of injuries to fish, provided the parameters needed for a rigorous evaluation of imaging technology.

The imaging technology evaluated included both tracking and imaging systems using acoustic technologies (such as sonar, for example DIDSON which is a multi-beam sonar array) and optic technologies (such as pulsed-laser videography, which is high-speed videography using laser as flash; see Figure 3-7). Criteria for determining image data quality such as frame rate, target detectability, and resolution were used to quantify the minimum requirements of an imaging sensor. We based our calculations on the most demanding application—imaging head injuries to a subyearling Chinook salmon smolt passing through the runner tip region. We concluded that a high-speed optical-imaging solution, such as pulsed-laser videography, was the only feasible technology to image fish fast enough and at high enough resolution to detect operculum and eye injuries inflicted to the fish when within the runner tip region. Only a laser light source would produce enough light in the extremely short exposure required to prevent image blur of the runner or the fish, which were moving at up to 32 m/s through the runner tip region. A project completion report will be issued in FY 2005.

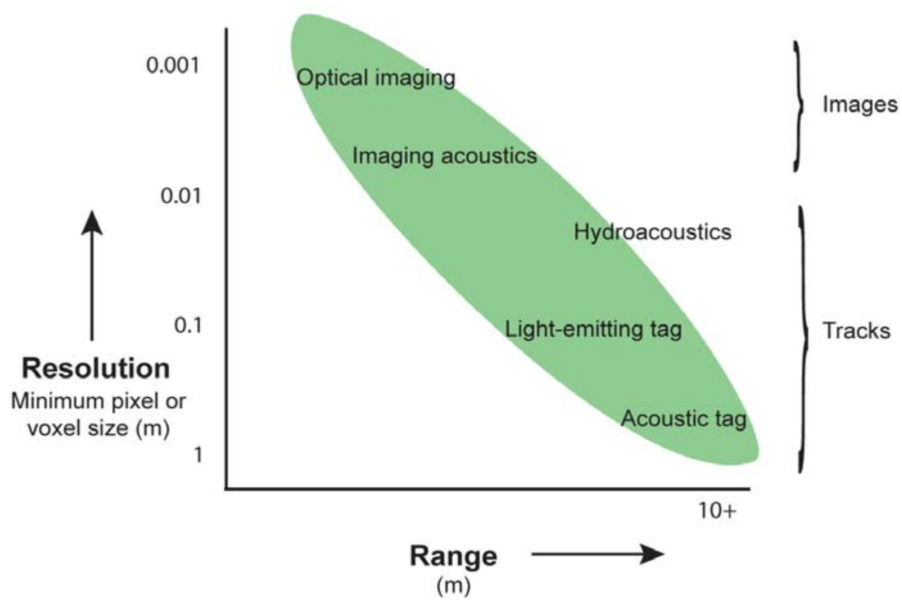


Figure 3-7. Turbine tracking and imaging technologies, showing tradeoffs between range, resolution, and data type.

3.2.3.3 Sensor Fish Development

Sensor fish activities were in two main areas in FY 2004. The 3DOF (degree of freedom) sensor fish developed over the last few years was downsized to fit more easily through the pipe injections systems used to introduce live test fish and sensor fish into turbine intakes and other fish passage environments, such as spillways. This sensor was deployed for fish passage assessment studies at the following facilities within the Columbia River basin: Ice Harbor Dam, The Dalles Dam, Wanapum Dam, and North Fork Dam. The 3DOF sensor fish were also used in laboratory studies to identify features in acceleration and pressure time histories indicative of impact of sensors on stationary structures and exposure to strong shear and turbulence.

Changes in the availability of silicon angular velocity(ies) in FY 2004 permitted inclusion of angular acceleration into the same package designed to downsize the 3DOF sensor fish. Using this technology, a 6DOF sensor fish has been designed, prototyped, tested, and put into production. The 6DOF sensor angular and linear accelerometers are sufficient to completely describe the motion of the sensor fish. Of particular importance is assessment of the angular acceleration that is a feature of flow below the runners of Kaplan and Francis turbines. These angular accelerations, while mathematically described, have not previously been directly measured for full-scale turbines.

The sensor fish releases planned for characterization of the fish passage environment for original and advanced design turbines at Wanapum Dam in FY 2005 will be the first data sets of their kind. These data sets will be a valuable aid for validation of CFD modeling of turbine flow and to describe the angular accelerations fish experience when passing through Kaplan turbines.

Also completed in FY 2004 were devices to calibrate the pressure and triaxial linear and angular accelerometers in the new 6DOF sensor fish. Acceptance testing and calibration of sensor fish devices to be used during field trials in FY 2005 includes the use of the testing jigs in conjunction with high-speed videography for the accelerometers. Fiduciary marks were put on sensor fish and tracked during processing of high speed video records of calibration trials. These data sets were compared with the output of the calibration jigs and sensor fish accelerometers. Initial testing conducted the last quarter of FY 2004 shows the performance of preproduction prototype 6DOF sensor fish device tri-axial linear and angular accelerometers to be well within acceptable error limits.

3.2.4 Environmental Analysis

3.2.4.1 Environmental Performance Testing

A draft report, *Framework for Environmental Performance Testing at Hydroelectric Power Plants*, has been written that considers the reasons for implementing a change in project structures or operations, ways of expressing environmental performance goals, and methods for detecting changes in environmental performance. The framework includes flowcharts for determining the level of information needed to test the turbine and brief descriptions of tools (measuring techniques, models, laboratory, and field tests) that can be employed. Some of these tools will be employed to analyze the performance of advanced turbines at the Osage Plant and Wanapum Dam.

4. TECHNICAL APPLICATION

The two research areas under Technology Application are Systems Integration and Technology Acceptance (Section 4.1) and Supporting Engineering and Analysis (Section 4.2). The project areas within these research areas are listed and a discussion of the status of each project is presented thereafter. See Contents, page vii (Section 4), for a complete list of the projects.

4.1 Systems Integration and Technology Acceptance

The project areas under Systems Integration and Technology Acceptance are as follows:

- Hydro/Renewables Integration (Section 4.1.1)
- National Coordinating Committee (Section 4.1.2)
- Integration and Communications (Section 4.1.3).

4.1.1 Hydro/Renewables Integration

Owing to its competitive and decreasing costs, coupled with the fact that it is a clean energy resource, wind energy capacity is likely to grow rapidly over the next two decades. As the penetration of wind energy increases, issues relating to grid integration and electric system reliability become increasingly important. Hydropower resources are uniquely capable of addressing these grid-integration issues, due to the characteristics of the generators and the built-in energy storage that accompanies hydro impoundment. Because of the opportunity for synergistic operation, the Department of Energy is actively investigating the opportunity to integrate wind energy with hydropower.

Large transmission grids are typically broken into several smaller transmission *control areas* in which reliability requirements are met while balancing loads with generation. Within any given control area, there may be several different types of generators, including wind and hydropower units. The average load within a control area typically varies in predictable daily and seasonal patterns, yet within that average is an unpredictable component of random load variation and unforeseen events. To compensate for these variations and unforeseen events and maintain reliability, steps are taken to bring additional generation capacity on line to provide regulation (for the random load fluctuations) or to set aside the capacity as reserves (to meet load forecast errors, unforeseen events, and unplanned outages). Together, the reliability services of regulation and reserves are termed ancillary services. Some generators within an electrical system, such as combustion turbines or hydro generators, can respond quickly to load fluctuations and can be started quickly. These agile generators are the type used to provide regulation and load on an hourly basis. The ability to provide ancillary services above and beyond the energy produced while operating is of economic value to a generator.

Introducing wind generation into a control area can increase the regulation burden and need for reserves, due to its natural intermittency. To accurately determine the impact on control area reliability and the consequential incremental increase in need for ancillary services, wind generation must be analyzed in the context of the transmission grid, fully encumbered with all of its loads, generators, and their corresponding characteristics. Hydropower, being a responsive generation resource capable of providing ancillary services, can be partnered with wind energy to supply the incremental increase in ancillary services. However, hydropower operations may be quite constrained by facility functions, which typically have higher priority than power generation. Thus, the study of wind and hydropower generation is characterized by three components:

1. Determine the impact on the control area reliability and need for ancillary services of wind integration

2. Analyze the physical and economic potential for providing the ancillary services and energy storage by the hydropower facilities
3. Ascertain the impact and potential benefits of wind integration on hydropower and hydrologic operations of the hydro facilities.

Figure 4-1 shows a likely configuration for integrating wind and hydropower generation. The wind and hydropower facilities may be located anywhere within the control area, provided no transmission constraints exist (note that other configurations are possible). While the plants are run independently, the integration of the resources comes within the control area, in serving the load and maintaining the system reliability. Thus, the transmission control area is the primary context within which wind and hydropower integration is considered.

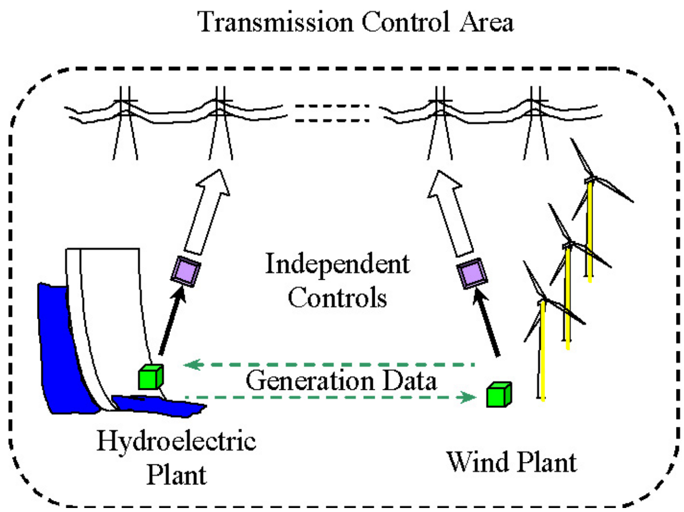


Figure 4-1. A likely configuration for integrating wind and hydropower facilities within a transmission control area.

Wherein wind and hydropower integration activities in FY 2003 focused on identifying potential sites and partners for studying integrated wind and hydropower operations, FY 2004 activities focused on initiating studies and an international collaboration through the International Energy Agency. The studies selected represent some of the diversity found in hydro facilities and control areas throughout the United States, with the hope of covering a breadth of integration issues. Each activity is briefly described below.

4.1.1.1 Missouri River Wind/Hydro Integration Study

The essence of this Missouri River project is to analyze the potential for, and study the impact of, integrating wind power in the Western Area Power Administration (WAPA) control area, which is supplied in part by electricity from six large hydro facilities on the Missouri River. These hydropower plants have a total nameplate capacity in excess of 2400 MW. The objectives of this project are to create a realistic wind generation scenario for North and South Dakota in wind development *zones* identified by WAPA, and to determine the incremental impacts of varying levels of wind generation on operation and scheduling in the WAPA control area, including next-day scheduling of hydro-generation resources and impacts of forecast errors on operation of the river system. The goal is to answer such questions as how does the variability of wind generation and uncertainty of forecast fits or not fit with current operational practices, and at what point does wind become problematic for current procedures? EnerNex Corporation and Wind on the Wires are the primary investigators in this project. The project was initiated during the summer of 2004 and is expected to be completed in 2005.

An important aspect of integrating wind energy on the utility grid is the nature of its variability. Figure 4.2 presents an example result from this project showing wind plant output variability. Built from a high-resolution simulation of meteorology for calendar year 2003 in WAPA-defined wind development zones, this figure shows the one-hour generation changes of a 100-MW wind farm located either in one area or spread out geographically. As can be seen, spreading the wind generation over a large geographic area rather than installing all the turbines in one location can significantly reduce the output variability, and consequently the need for ancillary services and impact on the hydro facilities providing those services.

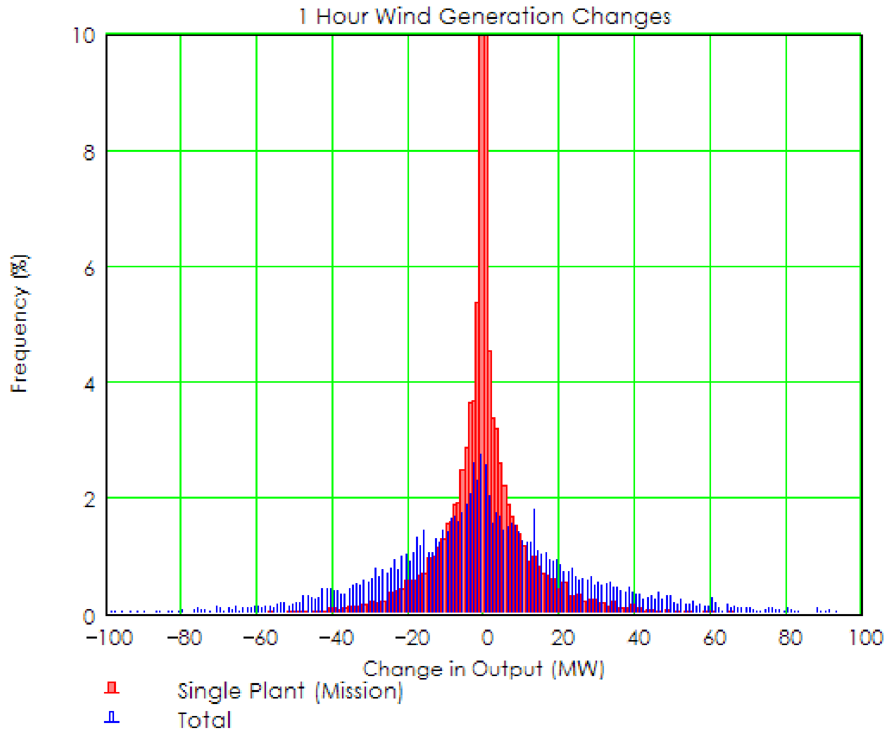


Figure 4-2. One-hour generation changes of a 100-MW wind farm located in one area versus spread out geographically.

4.1.1.2 Arizona Power Authority Wind/Hydro Integration Study

In order to best serve its customers and the citizens of Arizona, the Arizona Power Authority (Authority) is interested and authorized to study ways to make the best use of its federal hydropower allocation and transmission rights. The potential to combine hydropower generation with renewable energy generation, in particular wind energy, offers a potential benefit to the Authority's customers and, possibly, to the operators of the hydropower facilities and other interconnected parties. The Authority, as a Hoover Power customer, has an annual/monthly power allocation or entitlement and is interested in using it to allow for the integration of wind power and other renewable energy resources into its electric resource base, if economically feasible and without adverse impacts to its customers. This means that the Authority would use a portion of its Hoover allocation to provide ancillary services for the wind power, and perhaps allowing for resource storage (energy and water) in Lake Mead. Given the flexibility built into the operation of Hoover, it is very likely the hydropower facilities could support wind power integration. However, there are several important issues "surrounding" and effectively controlling whether or not this wind/hydro integration can occur successfully and economically. These include the laws and regulations, organizations and affected stakeholders (in particular, of the services supplied by Hoover), and existing contracts, agreements, compacts, and treaties. Each of these issues needs to be considered in order to truly demonstrate the feasibility of the wind/hydro integration and to justify proceeding further with an in-depth feasibility study.

The Authority, in conjunction with Northern Arizona University and NREL, is the principal investigator on this project. During FY 2004, the Authority completed a prefeasibility study to ensure the concept of integrating wind energy with their hydro allocation was possible, and to identify the necessary activities and parties that need to be involved in a feasibility study. Because Hoover Dam is a Bureau of Reclamation facility and the power from it is transmitted along WAPA power lines, these to organizations will be involved in the study. The prefeasibility study demonstrated there are no major institutional or legal obstacles to the Authority integrating wind with their hydro allocation. It is expected that a full feasibility study will be initiated in FY 2005.

4.1.1.3 Grant County Public Utility District in Washington State Study

Grant County Public Utility District 2 (the District) of Grant County, Washington, is interested in studying ways to expand its wind energy generation through effective integration with its hydropower operations. The District is a consumer-owned utility in a rural, predominantly agricultural region, and it owns and operates the two-dam Priest Rapids Project on the Columbia River in central Washington. Together, Priest Rapids and Wanapum make up one of the nation's largest hydropower developments, with the capacity to produce about 2,000 megawatts of electricity—enough to supply a city the size of Seattle—and the capability to produce 604 aMW of energy under critical water conditions and 785 aMW of energy under average water conditions. The District shares the Priest Rapids Project's affordable electric power with 12 Northwest utilities, which serve millions of customers, creating economic benefits throughout the Northwest. Currently, the District receives 36.5% of the output of the Project.

In addition to its hydropower generation, the District also purchases 12 MW (18.88% share) of the 63.7-MW Nine Canyon Wind Project. The District integrates the wind output by a dynamic signal into the its control area, essentially outputting to the Priest Rapids Project's pond. The ability to combine hydropower with wind power beyond the current level offers potential benefits to the District's customers and, possibly, to other interconnected parties. The study has two primary goals: to understand the impacts and costs of the District's current effort to integrate wind and hydropower, and to study the potential for expanding their wind integration. In addressing these goals, effort will be devoted to understanding the impacts of wind integration on the District's hydro operations, including identifying potential benefits and determining the costs of integrating wind with hydropower generation (e.g., ancillary service costs). In collaboration with Northern Arizona University and NREL, the District is the principal investigator on the project. The work plan was devised in FY 2004, and work will start in FY 2005.

4.1.1.4 International Energy Agency Annex XXIV Integration of Wind and Hydropower Systems

Worldwide, hydropower facilities possess a significant installed electric generating capacity. International Energy Agency (IEA) statistics indicate that at the end of 2001 there was in excess of 450,000 MW of installed capacity within IEA member countries, with about half in Europe and half in North America. In contrast, utility-scale wind power is relatively new in the electric market, with just over 36,000 MW installed (2004), but it is currently the fastest growing energy source in the world. Of this wind generating capacity, about 80% is installed in Europe and 20% in North America.

Recognizing the potential for synergistic operation of wind and hydropower facilities, many countries are beginning to investigate the opportunity to integrate wind and hydropower systems in order to optimize their output. The hope is to realize such benefits as lowering the cost of ancillary services required by wind energy, taking advantage of the built-in energy storage available at hydro facilities, more effectively using existing hydro and transmission facilities, and improving hydrologic operations to achieve an overall energy supply portfolio that is cleaner and more diverse and robust. To accelerate the process of realizing these benefits, the United States has led an effort to establish an international collaboration (an "Annex") under the auspices of the IEA Wind Implementing Agreement.

The primary purposes of the Annex are to conduct cooperative research concerning the generation, transmission, and economics of integrating wind and hydropower systems, and to provide a forum for information exchange. The Annex was approved by the IEA at the end of FY 2004, with its work plan set to begin during FY 2005. Six to eight countries are expected to participate in the Annex. The National Renewable Energy Laboratory and Northern Arizona University are the lead organizations in the Annex.

4.1.1.5 Bonneville Power Administration Wind Integration

In addition to the projects discussed above, Bonneville Power Administration (BPA) continues to address wind and hydropower integration. BPA has undertaken extensive research and development to evaluate the costs and opportunities associated with integrating wind energy into the Federal Columbia River Power System. The result of this evaluation is two new services that will use the flexibility of the hydro system to integrate wind energy into the BPA control area on behalf of electrical utilities in the Pacific Northwest. The first service, “Network Wind Integration Service,” is designed to serve the needs of public power customers with loads embedded in the BPA control area that elect to purchase all or a portion of their power from a new wind resource. The second service, “Storage and Shaping Service,” is designed to serve the needs of utilities and other entities outside of the BPA Control Area who have chosen to purchase the output of a new wind resource but do not want to manage the hour-to-hour variability associated with the wind output. BPA has established a goal of providing up to 450 MW (nameplate) of wind integration services over 2004-2011. At least 200 MW of these services will be earmarked for public power customers.

4.1.2 National Coordinating Committee

A cross section of the hydropower industry was contacted to discuss the potential organization of a national coordinating committee. A final report with conclusions and recommendations is scheduled to be issued in early 2005.

4.1.3 Integration and Communication

Transfer of new information to the hydropower community has always been an important component of the DOE hydropower program. The program accomplishes this transfer by participating in technical conferences, publications, ad hoc meetings to coordinate interagency research activities, and in on-call assistance from DOE and national laboratory staff. The publications generated as part of this technology transfer function are cited in the text and are listed in the References Cited section of this annual report. Hydropower program personnel were involved in the following activities during FY 2004.

4.1.3.1 Program Reviews and Planning Documents

Three program review, planning, and implementation meetings were conducted (February 2004, March 2004, and September 2004). The planning documents prepared include the *Hydropower Program FY 2004 Annual Operation and Management Plan*, a *Draft Hydropower Multi-Year Technical Plan*, field work proposals, and detailed work plans.

4.1.3.2 Program Performance Measurement

ORNL staff established a series of technical contacts among other federal hydropower agencies to evaluate interest in new interagency collaboration to build a consistent and comprehensive hydropower database describing the federal and nonfederal hydropower base in the United States. Such a database is needed to support planning and performance measurement of the DOE program in the future. We confirmed that such a database does not exist and that FERC, COE, Bureau of Reclamation, and USGS are all interested in working together to build it.

4.1.3.3 Program and Peer Review

The hydropower program conducted an independent technical assessment and peer review in June 2003 that obtained an industry evaluation of program activities. The peer review committee report was issued in September 2003. After the program evaluated this report and prepared responses and actions to address its issues, the report was finalized and issued in January 2004.

A program implementation meeting was held February 18–19, 2004 to present the numerous R&D projects within the Hydropower Program. Over 50 attendees from a wide range of government, industry, and environmental groups heard 32 presentations about the status of activities funded by the program. This meeting will help ensure that the various projects are coordinated and support the objectives of the program.

4.1.3.4 Technical and Interagency Coordination Meetings

During FY 2004, the Hydropower staff supported and participated in the following technical and interagency organizations and meetings: U.S. Army Corps of Engineers Turbine Working Group, United States Society on Dams, Low Impact Hydropower Institute, COE Anadromous Fish Evaluation Program, NOAA Fisheries' Watershed Ecology and Salmon Recovery Program, Independent Scientific Advisory Board for the Northwest Power Planning Council, International Energy Agency's Small Hydropower Annex meeting, Foundation for Water and Energy Education Annual Planning Meeting, and the Electric Power Research Institute's Annual Water and Ecosystems Group Meeting. Invited briefings were also delivered at several industry meetings.

4.1.3.5 Low-Impact Hydropower Institute

ORNL staff served as liaison between the DOE Hydropower Program and the Low Impact Hydropower Institute (LIHI) as a way to track emerging trends in certifying green hydropower projects. The list of hydropower projects certified by LIHI as "Low Impact" continued to grow in 2004. These projects include both small and large facilities, indicating that there is not a direct relation between project size and environmental impact.

4.1.3.6 Conferences and Workshops

Staff from DOE, INL, ORNL, and PNNL participated with and served on the organizing committees for several annual meetings, including the National Hydropower Association's Annual Conference in Washington, DC, and the HydroVision 2004 conference. Other conference/workshop participation in FY 2004 included the Northwest Salmon Recovery Workshop, Ecologically Sustainable Water Management Workshop, POWER-GEN Renewable Energy Conference, NorthAmerican Wildlife and Natural Resources conference, Hydrovision Biennial Conference, American Fisheries Society Conference, Fourth World Fisheries Congress, Trinity River Restoration Program Workshop, 2004 World Water and Environmental Resources Congress, 5th International Symposium on Ecohydraulics Conference, Optimization Workshop, World Renewable Energy Congress, and Ecologically Sustainable Water Management workshop: A Framework for Developing Sustainable Water Management Solutions in Hydropower Dam Licensing Proceedings before the Federal Energy Regulatory Commission. In many cases, staff served on advisory committees, organization committees, or as session chairs for these conferences.

4.1.3.7 Communications

The hydropower program develops and maintains a communications plan. One of the major communication activities during FY 2004 was to produce a publication titled "Hydropower─Setting a Course for Our Energy Future."

4.1.3.8 Education and Other Outreach

Elsevier published the *Encyclopedia of Energy* in March 2004. It includes sections on Hydropower Technology (Peggy Brookshier), Hydropower Resources (Garold Sommers), and Environmental Impact of Hydropower (Glenn Cada, Mike Sale, and Dennis Dauble).

Three chapters are in the final stages of authorship or co-authorship for a book on hydropower in the Columbia River. Chapters on salmon migration (Coutant and Richard Whitney), history of mitigation (Whitney and Coutant), and monitoring and evaluation (Lyman McDonald and Coutant) are nearly complete and have been submitted to the editor. The book will be published in 2005.

Chuck Coutant and Mike Sale briefed staff of the Office of Wind and Hydropower Technologies and others at DOE headquarters on Pacific Northwest salmon and hydro issues. Chuck serves on the Northwest's Independent Scientific Advisory Board and the Independent Scientific Review Panel, which review and advise on salmon and dam work funded by DOE's Bonneville Power Administration and the Corps of Engineers.

The Hydropower Program supported the turbine contest at the HydroVision 2004 Conference with scholarship funds. The program supported the Foundation for Water and Energy Education’s Web-based animation tour, showing how hydropower projects work. During FY 2004, over 80 public inquiries for hydropower information were received and responded to.

Other outreach activities during FY 2004 included conducting a pumped storage project assessment for the Public Renewable Energy Partnership and the California Energy Commission, and participating in a meeting with the Alaska Energy and Environmental Office.

4.1.3.9 Web Site Development and Usage

The program maintains an official Hydropower Web site (http://hydropower.inel.gov). Several updates and enhancements were made to the site in FY 2004. Reports on the Program’s significant new research results were added, including the new DOE reports cited in this Annual Report. Other papers that program staff published in professional and trade journals over the past year are also available on the Web site.

The latest statistics on user access to the site indicate steady interest and access by users worldwide. During a peak period, between November 2000 and September 2001, the hydropower Web site received a total of 758,300 hits, and averaged 69,000 hits per month.

4.1.3.10 Proposal Review

DOE received several unsolicited proposals throughout the year, including research and development ideas for unconventional turbine technology. National laboratory staff and DOE conducted technical reviews of these proposals and responded with comments to the proposers. The proposers were also advised of current and planned solicitations, so that they could participate in this process.

4.1.3.11 Small Business Innovation Research and Small Business Technology Transfer

The Office of Energy Efficiency and Renewable Energy expanded and diversified its request for R&D proposals for advances in energy efficiency and renewable energy technologies through the Department of Energy’s FY 2004 Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR). One of the solicitations included concepts for low-head hydropower systems. This grant solicitation is for development and implementation of innovative, cost effective, and environmentally acceptable concepts for low-head hydropower energy systems for the production of electricity.

The INEEL provided technical support in evaluating the proposals received in response to the SBIR/STTR *Low Head Hydropower Systems Solicitation*. One project was selected under this solicitation.

4.2 Supporting Engineering and Analysis

The project areas under Supporting Engineering and Analysis are as follows:

- Valuation Methods and Assessments (Section 4.2.1)
- Innovative Technology Characterization (Section 4.2.2).

4.2.1 Valuation Methods and Assessments

ORNL staff organized a panel at the World Renewable Energy Congress in Denver in September 2004, "New Directions in Hydropower." Four papers were presented: "Environmentally Preferable Power: an Emerging Tool for Policy Makers," "Best Practice Guidelines for Hydropower Performance and Implications for Gains in Incremental Power," "Development of an International Green Standard for Small-Scale Hydropower," and "Hydropower Pluralism in Nepal: Enhancing Social and Environmental Justice." This technical session was well-received and is an important step forward in showing that hydropower belongs among the renewable energy technologies.

4.2.2 Innovative Technology Characterization

4.2.2.1 Tidal Energy Project – Verdant Power

ORNL staff has been assisting Verdant Power, LLC prepare for a permit from the U.S. Army Corps of Engineers to install an experimental array of submerged kinetic energy turbines in the heavily industrialized East River in New York City. This innovative, no-dam hydropower technology is in the permitting phase for a 6-unit system of windmill-like blades erected on pilings in the East Channel (Roosevelt Island Tidal Energy Project; RITE). The operational and environmental information developed would be used to prepare a FERC license application for a more extensive installation of kinetic turbines. The COE permitting process involves extensive consultations over environmental effects with the NY Department of Environmental Conservation, U.S. Fish and Wildlife Service, National Marine Fisheries Service, and Coast Guard.

The work is funded outside the DOE Hydropower Program but closely integrated with it. A State Partnerships Program grant by the ORNL Energy Efficiency and Renewable Energy Program has been used to assist in evaluating the project under the auspices of the New York State Energy Research and Development Administration, which is partially sponsoring the project.

Staff involvement included participation in teleconferences with Verdant Power and agency staffs to help identify the types of environmental information that will need to be collected as part of the project. The most difficult task is quantifying the interactions between fish (potentially including endangered species) and the turbines that would be submerged in the turbid East River. A protocol was drafted for a mobile hydroacoustics study at the site that could be used to ascertain whether or not fish strike is a serious issue. Also, a protocol and a literature review were drafted for evaluating the effects on aquatic life of sounds potentially generated by the project. Public and agency concerns about the turbine array have centered on effects to navigation, fish strike, and water quality/sediment mobilization. ORNL staff has assisted Verdant and its contractor, Devine Tarbell and Associates, Inc., with responses to agency comments. Because this is a unique and innovative technology, relevant available information on environmental effects is scant and agency questions have been extensive; a detailed monitoring program has been prepared.

4.2.2.2 Low-Power Hydropower Resource Assessment and Technology Development

This project established a technical advisory committee and held two meetings during the year: a full-day meeting in Las Vegas on March 3, 2004 and a half-day meeting in Montreal, Canada on August 17, 2004. Sixteen people attended the first meeting, representing various elements of the U.S.

hydropower community and environmental interests. Fifteen people attended the second meeting, representing various elements of the U.S. and Canadian hydropower communities. No environmental representatives attended this meeting. The principal subjects addressed in the first meeting were the result of the water energy resource assessment issued in draft in October 2003 and the project five-year plan. The principal subjects discussed in the second meeting were the feasibility assessment of water energy resources in the Pacific Northwest (PNW) Hydrologic Region; a virtual hydropower prospecting tool (a geographic information system application for viewing water energy resource sites in the context infrastructure, population centers, land ownership and use); and a catalog of low-power hydropower technologies to be made available on the Web (accompanied by a search application to retrieve technology listings of interest). Meeting notes were issued to attendees after each meeting.

The initial objectives of the project task to assess the water energy resources of the United States were to estimate the power potential of the country's water energy resources in various power classes and to show the relative concentrations of these resources. The project produced a draft report in October 2003, and issued it for review to members of the project's Technical Advisory Committee and members of the DOE Hydropower Program team. The final report, *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources*, was issued in April 2004. The body of the report presents results for the entire country, a summary of which is shown in Figure 4-3. The figure shows how the estimated 290,000 MW of total U.S. water energy resources is divided between developed, excluded, and available potential and how the 166,000 MW of power potential is divided among three power classes. Appendix A of the report presents the results for each of the 20 U.S. hydrologic regions. Appendix B presents the results for each of the 50 states. Appendix C presents the results of a very limited validation study. The report is accessible at the Hydropower Program Website at: http://hydropower.inel.gov/resourceassessment/.

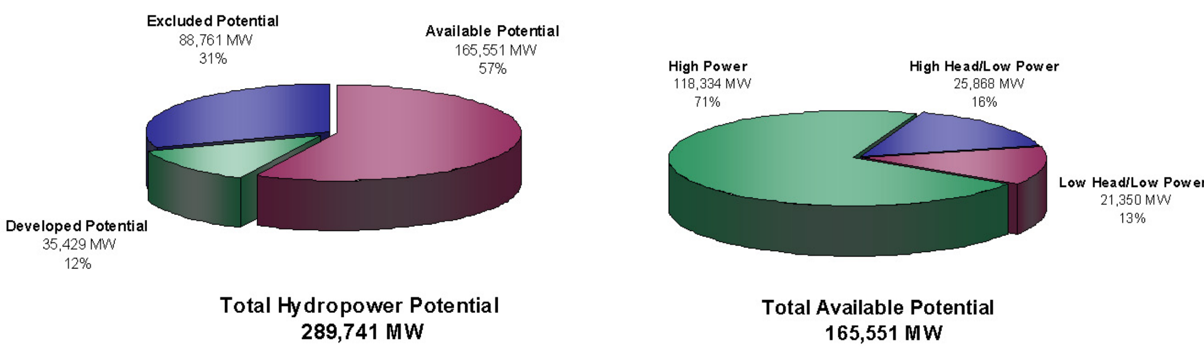


Figure 4-3. (a) Total hydropower potential (annual mean power) of United States water energy resources divided into constitutive power categories, (b) total hydropower potential (annual mean power) of available[a] United States water energy resources divided into constitutive power classes.[b]

The next phase of the resource assessment task was initiated, which is to assess the feasibility of developing the water energy resources identified in the study published in April and to estimate their hydropower potential considering realistic development criteria. The The Pacific Northwest Hydrologic Region was chose as the study area for a pilot feasibility assessment during which the technical approach for the nationwide feasibility assessment will be defined. Selection criteria were defined to identify stream reaches that are prime candidates for development. Development criteria were also defined to

[a] *Available* refers to resources that have not been developed and are not excluded from development by federal statutes and polices. Additional considerations may make development of an "available" resource unlikely.

[b] *High power* and *low power* refer to power potential greater than or equal to 1 MW and less than 1 MW, respectively. *High head* and *low head* refer to having a hydraulic head greater than or equal to 30 ft or less than 30 ft, respectively.

obtain a better estimate of the true hydropower potential of prime candidate reaches. These selection and development criteria were applied to PNW Region water energy resource sites, resulting in an initial set of prime candidates and the corresponding total hydropower potential. These preliminary results were presented at the second Technical Advisory Committee meeting. The large reduction in hydropower potential relative to the total gross power potential of the candidate reach population indicates that the selection and development criteria were too conservative. In order to refine the criteria, the low-power and small hydro plant populations of the region were analyzed. A methodology was determined for identifying already-developed stream reaches resulting from installation of a hydroelectric plant.

The initial step in the project's task to assess low-power hydropower technology was to inventory the technology in this power class worldwide. The approach taken was to solicit information from vendors and technology developers for a low-power hydropower technology catalog of technologies in various stages of development, ranging from concept to commercially availability (see Figure 4-4). The incentive for providing the information was worldwide exposure of their technology in the catalog, available over the Internet.

Conducting the inventory and publishing the results in a reference document supports several objectives:

- Provides the program with a preevaluation of the state of the art
- Obtains information for an initial gap analysis to identify requirements and operating conditions not supported by existing technologies, thus providing direction for the program's future R&D
- Obtains information needed for an engineering assessment of the technologies
- Assists potential developers in their search for applicable technologies
- Compares the state of U.S. technology development in this area with that of other countries
- Facilitates communication between low power technology stakeholders, including technology developers, researchers, site developers, investors, government agencies, and environmentalists.

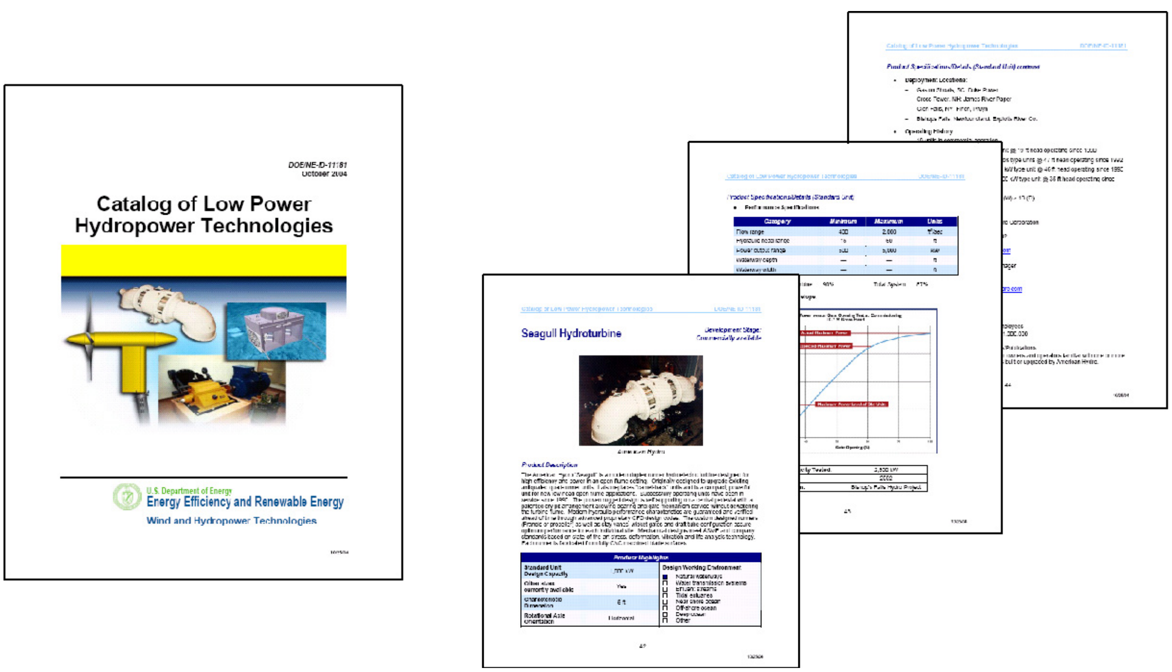


Figure 4-4. Cover of the *Catalog of Low Power Hydropower Technologies* and typical three-page technology listing.

In order to obtain the information, the project developed an easily completed Web form, through which graphics (pictures and graphs) could be transmitted as well. The form was posted on the Hydropower Program Website, and invitations to for information were ultimately sent to 180 companies and individuals. A format was developed to standardize recording of the input received for each technology, and the data from each Web form received was put into the format. A database was also developed to store the information received, and a computer application was developed to display the catalog and to search it for listings of interest based on any combination of six search criteria. The initial version of the catalog with 20 listings and development of the Website for its use were nearly ready for launch on the Web at year's end.

In order to facilitate use of the information produced by the assessment of water energy resources of the United States, the project developed a pilot CD-based GIS tool to view the location of resource sites of the PNW Region in context (see Figure 4-5). This virtual hydropower prospecting tool displays the resource sites on a map and provides the ability to also display context information, including hydrography; topography; roads, and railroads; power infrastructure, including power plants of all types, power lines, and substations; exclusion zones where development is highly unlikely; population centers and cities; and federally controlled lands. In addition to being able to display these features, the user can obtain attribute information about any specific feature and can search for features using key words or proximity to a selected feature. The pilot version was distributed to members of the project Technical Advisory Committee for review shortly after the second committee meeting.

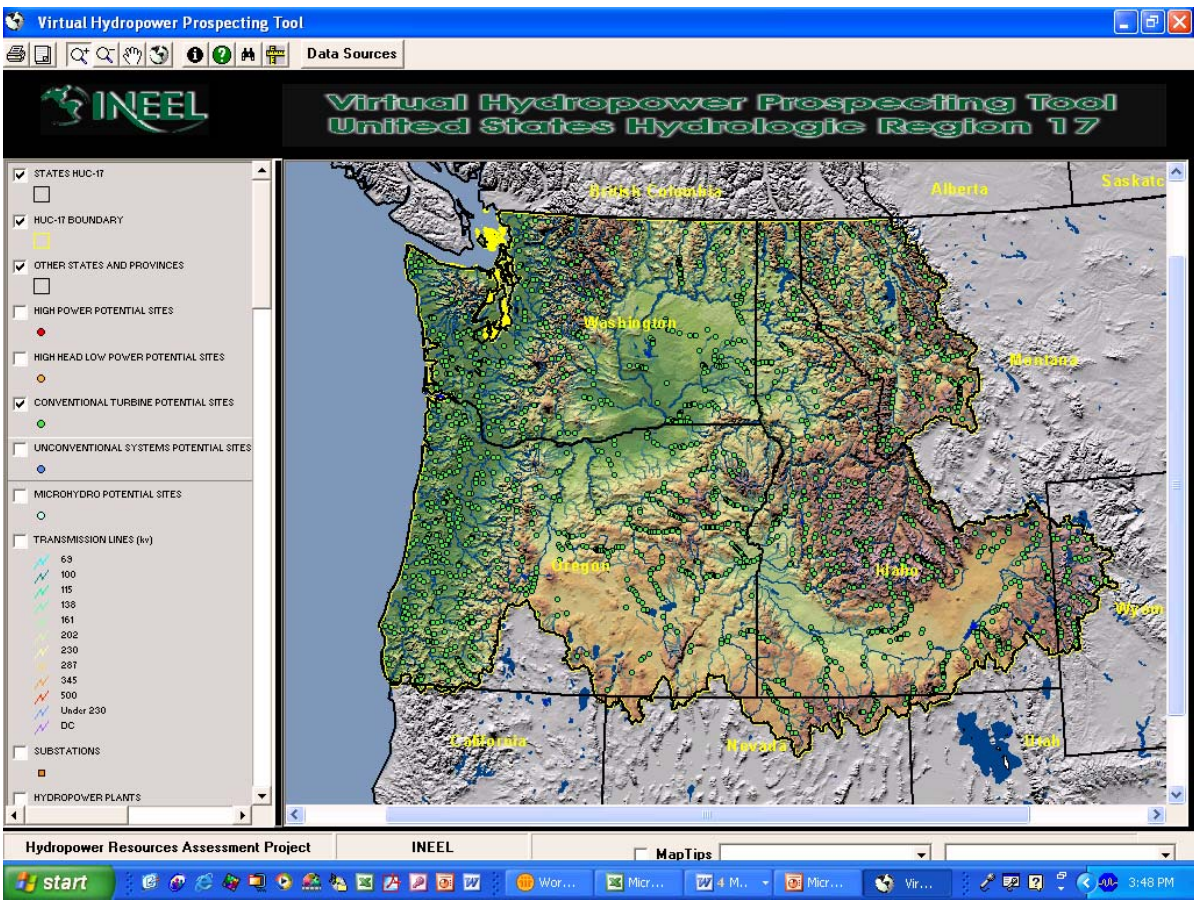


Figure 4-5. Computer desktop showing virtual Hydropower Prospecting Tool display.

5. FUTURE ACTIVITIES

The DOE Hydropower Program activities in all four areas (Advanced Hydropower Technology, Supporting Research and Testing, Systems Integration and Technology Acceptance, and Supporting Engineering and Analysis) will continue in future years. For example, the Large Turbine Field Testing area will support environmental and engineering studies at the Osage Project, Box Canyon Project, and Wanapum Dam, as well as field and physical model studies of COE turbines. Biocriteria studies, computational modeling, and development of advanced instrumentation are all critical to understanding the results of the large-turbine field testing and will be continued. Many of these supporting studies will focus on the potential fish injury mechanisms of turbulence and strike.

The Water Use/Operations Optimization task will determine how electricity production can be increased at a given hydropower plant by optimizing such aspects of plant operations as the settings of individual units, multiple unit operations, and release patterns from multiple reservoirs. The Improved Mitigation Practices task will continue to investigate the environmental benefits, economic costs, and overall effectiveness of mitigation practices intended to improve fish passage at dams, enhance fish habitat and water quality through flow modification, and provide better environmental conditions for redd (nest) success. Mitigation practices that are selected based on sound scientific evidence should reduce costs while maximizing environmental benefits.

DOE-HQ supports or sponsors various activities during the year, such as the Small Business Innovative Research (SBIR), Office of Science and Technology Information (OSTI), and the Hydropower Turbine contests at HydroVision and Waterpower conferences. These activities help maintain the prominence of the DOE Hydropower Program within the hydropower industry.

Technical outreach will continue with staff participation in conferences, workshops, technology transfer activities, and program reviews. Accomplishments of the Hydropower Program will be distributed by technical reports and peer-reviewed publications. The Hydropower Program Web sites (http://eeredev.nrel.gov/windandhydro/ and http://hydropower.inel.gov/) will remain a primary means for the hydropower industry and regulatory and resource agencies to access these publications. Assessment of low head/low power resources in the United States and analysis of innovative technologies that can capitalize on those resources will continue. From insights obtained during the program peer review, DOE will determine the value of formulating a Hydropower Coordinating Committee. This committee would consist of representatives from other government agencies and nongovernment organizations. The purpose of this committee would be able to provide additional direction to the Hydropower Program.

6. PUBLICATIONS AND PRESENTATIONS IN FISCAL YEAR 2004

Publications that can be downloaded from http://hydropower.inel.gov are followed by an asetreik.

6.1 Publications

Cada, G. F., M. G. Ryon, D. A. Wolf, and B. T. Smith, *Development of a New Technique to Assess Susceptibility to Predation Resulting from Sublethal Stresses (Indirect Mortality),* ORNL/TM-2003-195, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 2003.*

Cada, G. F., T. J. Carlson, D. D. Dauble, R. T. Hunt, M. J. Sale, and G. L. Sommers, *DOE Hydropower Program Annual Report for FY 2003*, DOE/ID-11136, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies, February 2004.*

Cada, G., J. Smith, and J. Busey, "Use of Pressure Sensitive Film to Quantify Sources of Injury to Fish," *North American Journal of Fisheries Management*, in press.

Cada, G., M. Sale, and D.D. Dauble, "Environmental Impact of Hydropower," in *Encyclopedia of Energy*, Vol. 3, San Diego: Elsevier Academic Press, 2004.

Deng, Z., M. C. Richmond, C. S. Simmons, and T. J. Carlson, *Six-Degree-of-Freedom Sensor Fish Design-Governing Equations and Motion Modeling,* PNNL-14779, July 2004.*

Ge, L., and F. Sotiropoulos, "3D Unsteady RANS Modeling of Complex Hydraulic Engineering Flows, Part I: Numerical Model," to appear in *ASCE Journal of Hydraulic Engineering*, 2004.

Ge, L., S. Lee, F. Sotiropoulos, and T. W. Sturm, "3D Unsteady RANS Modeling of Complex Hydraulic Engineering Flows, Part II: Model Validation and Flow Physics," to appear in *ASCE Journal of Hydraulic Engineering*, 2004.

Gilmanov, A., and F. Sotiropoulos, "A Cartesian Grid Algorithm for Simulating Fluid-Structure Interaction Problems with Application to Fishlike Swimming," submitted for publication to the *Journal of Computational Physics*, 2003.

Gilmanov, A., and F. Sotiropoulos, "A Hybrid Cartesian/Immersed Boundary Method for Simulating Flows with 3D Geometrically Complex Moving Bodies," submitted for publication to the *Journal of Computational Physics*, 2004.

Gilmanov, A., F. Sotiropoulos, and E. Balaras, "A General Reconstruction Algorithm for Simulating Flows with Complex 3D Immersed Boundaries on Cartesian Grids," *Journal of Computational Physics*, Vol. 191, No. 2, pp. 660–669, 2003.

Hall, D. G., S. J. Cherry, K. S. Reeves, R. D. Lee, G. R. Carroll, G. L. Sommers, K. L. Verdin, *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources*, DOE/ID-11111, Idaho National Engineering and Environmental Laboratory, April 2004, http://hydropower.inel.gov/resourceassessment/.*

Hanrahan, T. P., D. R. Geist, E. V. Arntzen, and C. S. Abernethy, *Effects of Hyporheic Exchange Flows on Egg Pocket Water Temperature in Snake River Fall Chinook Salmon Spawning Areas*, PNNL-14850, September 2004.*

"Hydropower: Setting a Course for Our Energy Future," U.S. Department of Energy, Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program, National Renewable Energy Laboratory, DOE/GO-102004-1981, 24-pp. brochure, July 2004.*

Neitzel, D. A., D. D. Dauble, G. F. Cada, M. C. Richmond, G. R. Guensch, R. P. Mueller, C. S. Abernethy, and B. Amidan, "Survival estimates for Juvenile Fish Subjected to a Laboratory-

Generated Shear Environment," *Transactions of the American Fisheries Society, Vol. 133, pp. 447–454.*

Paik, J., F. Sotiropoulos, and M. J. Sale, "Numerical Simulation of Swirling Flow in a Complex Hydro-Turbine Draft Tube Using Unsteady Statistical Turbulence Models," to appear in *ASCE Journal of Hydraulic Engineering*, 2004.

Paik, J., L. Ge, and F. Sotiropoulos, "Recent Progress in Simulating Complex 3D Shear Flows Using Unsteady Statistical Turbulence Models," invited paper, *Int. Journal of Heat and Fluid Flow*, Vol. 25, No. 3, pp. 513–527, 2004.

Ploskey, G. R. and T. J. Carlson, *Comparison of Blade-Strike Modeling Results with Empirical Data*, PNNL-14603, March 2004.*

Ryon, M. G., G. F. Cada, and J. G. Smith, *Further Tests of Changes in Fish Escape Behavior Resulting from Sublethal Stresses Associated with Hydroelectric Turbine Passage*, ORNL/TM-2003/288, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 2004.*

Sommers, G. L., *FY 2003 Hydropower Program Review*, prepared for the U.S. DOE Wind and Hydropower Technologies Program, January 2004 (internal report, available from the Department of Energy Hydropower Program).

Tang, H., and F. Sotiropoulos, "Fractional Step Artificial Compressibility Method for the Incompressible Navier-Stokes Equations," submitted for publication to the *SIAM Journal of Scientific Computing*, 2003.

Tang, H., S. C. Jones, and F. Sotiropoulos, "An Overset Grid Method for 3D, Unsteady, Incompressible Flows," *Journal of Computational Physics*, Vol. 191, No. 2, pp. 567–600, 2003.

Verdin, K. L., SAIC/EROS Data Center, *Estimation of Average Annual Streamflows and Power Potentials for Alaska and Hawaii*, INEEL/EXT-04-01735, Idaho National Engineering and Environmental Laboratory, May 2004.*

Weiland, M. A., and T. J. Carlson, *Technologies for Evaluating Fish Passage through Turbines*, PNNL-14437, October 2003.*

6.2 Presentations

Anderson, J., and K. Ham, "Quantifying Passage Stress Effects on Long-Term Fish Survival," *134th Annual Meeting of the American Fisheries Society, Madison, Wisconsin, August 2004.*

Bevelhimer, M. S., "Environmental Effects of Hydropower Dams: Research and Impact Assessment at Oak Ridge National Laboratory," *Environmental Engineering Seminar Series, Department of Civil and Environmental Engineering, University of Tennessee, February 4, 2004.*

Bevelhimer, M. S., M. J. Sale, and C. C. Coutant, "Balancing Fisheries Management and Conservation with Hydropower Production in Large Multi-Reservoir Systems," *Fourth World Fisheries Congress, Vancouver, BC, Canada, May 2-6, 2004.*

Cada, G. F., "Laboratory Studies to Specify Biological Criteria for Turbine Design," *134th Annual Meeting of the American Fisheries Society, Madison, Wisconsin, August 22–26, 2004.*

Cada, G. F., M. J. Sale, T. Carlson, F. Sotiropoulos, and B. Smith, Characterizing Turbulence and Its Biological Effects at Hydroelectric Power Plants," *5th International Symposium on Ecohydraulics, Madrid, Spain, September 12-17, 2004.*

Carlson, T. J. and J. A. Duncan, "In-Turbine and other Passage Route Measurements Using the Sensor Fish Device," *134th Annual Meeting of the American Fisheries Society, Madison, Wisconsin, August 2004*.

Dauble, D. D., "Advanced Turbine Design for Safe Fish Passage," *Northwest Salmonid Recovery Workshop, October 2003, Seattle,Washington*.

Dauble, D. D., "Lewis and Clark's Columbia River: 200 Years Later," National Military Fish & Wildlife Association, Spokane, Washington, March 2004.

Moursund, R. A, and M. D. Bleich, "Non-Visible External Fish Injury Detection and Quantification in Dam Passage Research," *HydroVision 2004, PNWD-SA-6379, Montrea, Canada, August 2004*.

Moursund, R., "Advanced Tools for Tracking Fish Behavior," *134th Annual Meeting of the American Fisheries Society, Madison, Wisconsin, August 2004*.

Mueller R. P., M. A. Weiland, and Z. Deng, "Characterization of Bead Trajectories through the Draft Tube of a Turbine Physical Model," *American Fisheries Society Annual Meeting, Madison, Wisconsin, August 2004.*

Paik, J., F. Sotiropoulos, and M. J. Sale, "Numerical Simulation of Flow in a Hydro-turbine Draft Tube Using Unsteady Statistical Turbulence Models," *22nd IAHR Symposium on Hydraulic Machinery and Systems, June 29–July 2, 2004, Stockholm, 2004*.

Ploskey, G. and T. J. Carlson, "Comparison of Blade-Strike Modeling Results with Empirical Data to Identify Effects and Uncertainties," *134th Annual Meeting of the American Fisheries Society, Madison, Wisconsin, August 2004*.

Richmond M. C, Z. Deng, W. A. Perkins, and C. L Rakowski, "Biomechanics Approach for Understanding Fish Response to Hydraulic Forces," *American Fisheries Society Annual Meeting, Madison, Wisconsin, August* 2004.

Richmond M. C, T. J. Carlson, J. A. Serkowski, C. B. Cook, and J. P. Duncan, "Characterizing the Fish-Passage Environment at The Dalles Dam Spillway," *ASCE World Water & Environmental Resources Congress, Salt Lake City, Utah, June 2004*.